PROCEEDINGS
THE INSTITUTION OF CIVIL ENGINEERS

PART I
JANUARY 1953

ORDINARY MEETING

4 November, 1952

ALLAN STEPHEN QUARTERMAINE, C.B.E., M.C., B.Sc. (Eng.), the retiring President, in the Chair

The President informed the Meeting, with great regret, of the death during the Institution recess of Lord Macmillan, an Honorary Member of the Institution. A resolution of condolence had been passed by the Council and conveyed to the members of Lord Macmillan's family.

The Council reported that they had recently transferred to the class of

Members

John Frederic Allan Baker.
Christopher Richard Brodrick Birdwood, B.A. (*Cantab.*).
Colin Francis Blatchford, B.E. (*W. Australia*).
Frank Lorimer Bruce.
Mathie Wallace Bryce, B.Sc. (*Glas.*).
Ian Cameron.
Vincent Harvey Collingridge.
Leonard Richard Creasy, B.Sc. (Eng.) (*Lond.*).
Derek Robert Robertson Dick, B.Sc. (Eng.) (*Lond.*).
Leslie Hugh Dickerson
Frederick Harold Dickinson, M.Eng. (*Liverpool*).
Edward Franks Driver, B.Eng. (*Sheffield*).
Evan John Evans, M.Sc. (Eng.) (*Lond.*).
Allan John Fairmaid, B.Sc. (*New Zealand*).
Henry Montague Finlay, B.A. (*Cantab.*).
Sir Clarence Johnston Graham, B.Sc. (*Belfast*).
William Moir Guthrie, B.Sc. (Eng.) (*Lond.*).
Arthur Salmond Hamilton, B.Sc. (Eng.) (*Lond.*).
John William Henderson, B.Sc. (*Durham*).
Percival Victor Hoare.
Philip William Hunt.
George Wesley Hutchinson, B.Sc. (*Durham*).
Robert Leslie, M.Sc. (*Cape Town*).
Thomas Whinney Longridge, B.Sc. (*Durham*).
John William Lovatt.
John Ross McGibbon, B.Sc. (*Glas.*).
Donald Henry May, O.B.E.
Frank Joseph James Prior, O.B.E.

Norman Frank Richards, B.Sc. (*Bristol*)
Donald Charles Robertson, B.Sc. (*Cape Town*).
Robert Douglas Robinson, (B.Eng.) (*Liverpool*).
Guy Taite Shoosmith, M.A. (*Cantab.*).
Ernest Loudon Smith, B.Sc. (*Glas.*).
William Paton Steele, B.Sc. (Eng.) (*Lond.*).
Francis Henry Stokes, B.Sc. (*Bristol*).
Peter Rudolf Swart, B.Sc. (*Glas.*).
Alexander Key Terris, B.Sc. (*Edin.*).
Vladimir Weber, B.Sc. (Eng.) (*Lond.*).
Matthew Cochrane White, B.Sc. (*Edin.*).
Charles Vivian Wolff, B.Sc. (*Birmingham*).

and had admitted as

Students

Christopher Sunday Olutunde Akande.
Colin Anderson.
John Leslie Andrew.
James Andrews.
Douglas Miller Angus.
Allen Annesley.
Elwyn John Ansell.
Robert Armstrong.
Robert Gordon Ashworth.
James Philip Axell.
Clifford Raymond Ayers.
Mohamed Hamid Ahamed Azhar.
Kenneth Alan Bailey.
Michael Thomas Harvey Banks.
Walter Waddell Bannerman.
Keith Edward Bell.
James Joseph Benton.
Harold Rowland Beswick.
Dennis Arthur Bicknell.
Ian Sanderson Bielby.
Patrick Malcolm Bird.
John Brian Blakeley.
Nicolaas Blankevoort.
Derek Bond.
Patrick John Bonser.
John Jefferson Booth.
Thomas John Bowman.
Dennis Alan Box.
Robin Brace.
Richard Walter Braddock
Raymond Muir Bremner.
Frank Brichta.
Anthony Clive Briggs.
Brian William Broderick.
George Ewan Brooks.
Leonard Brown.
Dennis Bertram Bullett.
Ian Hood Bullock.
Frederick George Burrows.
James Williams Byrom.
Ronald Francis Carney.
Graham Henry Cash.
Robert Christopher Chevassut.
James Chew.
William Michael Clark.
Eric William Clutton.
John David Colaco-Osorio.
Brian John Cole.
Bill Cecil Vivian Colverson.
William George Conchie.
Donald Lewis Cooke.
Desmond John Cooper.
Bryan Hubert Coulson.
Geoffrey Coulson.
Frank Cringle.
Andrew Skinner Davies.
John David Lenecre Davies.
Stanley Premkumar Davis.
John Davison.
Lawrence Leonard Daw.
Albert Manitou Leslie Dawe.
Derek Wallace Dean.
Peter Dean.
Robert Burns Dempster.
Basil Mervyn de Soysa.
Cecil Robert McIntyre Dewing.
John Sidney Dimmock.
Francis Newby Dinsdale.
John Veitch Dishington.
Victor Donald Dixon.
Anthony Dockerty.
Michael Charles Doody.
Brian Douglas-Jones.
David Grant Downie.
John Barry Downs.
Charles Scott Dunn.
Edward John Dymond.
Francis John Dyton.
James William Eades.
David Estcourt Edwards.
John Edward Ellis.
Robert Emmett.
Alan Stephen Frank Etherington.
Leonard Fairhurst.
Felix Oliver Feighan.
Harold Marflitt Fenby.
Hugh Martin Finnimore.
Thomas Fitzgerald.
John Trevor Forster.

David Richard Fussell.
Jolyon Fyfield.
John Galt.
Tom Edmondson Gartside.
John Arthur Gilbert.
Alexander Gilchrist.
Alexander McIntosh Gill.
John Francis Gillett.
David Tom Goodyear.
Ananda Amarasiri Goonewardene.
Ian Geoffrey Graham.
Malcolm Graham.
Malise John Graham.
Allan Mathie Green.
John Martin Green.
Charles Ian Robb Greer.
James Greig.
Bernard Francis Grice.
Sukumar Guha.
Colin Michael Guilford.
Leonard Cyril Gunawardana.
Peter James Terry Haines.
Harry Hall.
Stanley Frederick Hall.
Malcolm Hannah.
Michael Francis Hanrahan.
Edward George Harris.
Richard John Harris.
Donald Brian Harvey.
Keith Barnes Harvey.
Raymond Edward Harvey.
Theodore Francis John Hawkins.
John Stansfield Heys.
Peter Hobden.
Anthony William Hockaday.
Brian James Holder.
Robert Wilfred Hollands.
James Nigel Holmes.
David Aubrey James Hooker.
Barrie Scott Hookins.
Ivor Wilfred Hornby.
Geoffrey Howard.
John Keith Hunt.
John Alexander Jackson.
Michael Robert Jacobson.
David Malcolm James.
George Sinclair Jarvie.
Chandrasekera Wijayaratne Jayasinghe.
Balarajah Jeevaratnam.
Graham David Jenkins.
Ronald Dennis Jenkins.
Donald Graham Johnstone.
Tebuvanage Don Patrick Joseph.
David Trevor Jones.
Henry King James Jones.
Christopher David Kennedy.
Haakon Kierulf.
Rajaratnam Rajamanickam Kumarakulatungam.
Mohamed Yusuf Kureshy.
Rex Ivan Lancaster.
James George Arderne Latham.
Donald Lawton.
Geoffrey Stewart Leach.
Raymond Cecil Le Noury.
Peter Martin Le Patourel.
John Robert Lethbridge.
Archibald Carmichael Lindsay.
Lionel Lindsay.
Clifford Frank Lord.
James Lothian.
Albert Cree McAdam.
Dermot Peter McDermott.
Peter Graham Macdonald-Smith.
Kevin McGurk.
James MacInnes.
Robert John Mackay.
Hubert Jude Patrick Christopher McLaughlin.
John Gordon Makin.
James Sugden Marshall.
Lawrence Harold Martin.
Leslie Rajanathan Stanley Mather.
Colin Mercer.
Dowa Vena Mgudlwa.
Harry Middleton.
David Charles Miller.
Terence Roderick Mills.
Michael Raleigh Milns.
John Moffat.
Ezekiel Makhothatsa Mpote Mofokeng.
Peter Thomas Moore.
Edward Brian Morgan.
Geoffrey Albert Muscutt.
Mailvaganam Nadarasa.
Joseph Thurairatnam Nallaiah.
Subir Nandi.
Michael Oliver Naughton.
Kenneth Newman.
David Alfred North.
Terence O'Connor.
Gavin Ogilvie.
Thomas John Oldham.
David John Palmer.
Ernest Reginald Parsons.
Geoffrey Frank Parsons.
William Lunn Pattison.
Bernard Arthur Peacock.
Edmund Fedrick Marcus Perera.
Quintus St George Mathias Perera.
Gerald Eaton Phelps.
Nigel Dalton Pilgrim.
Howard Price.
Ambalavanar Ragunathan.
Koruwage Hemakirti Ranasoma.
Don Gamini Lakshman Ranatunga.
Arumugam Ratnarajah.
Gerald Patrick Raymond.
Norman Arthur Read.
Malcolm Randall Rees.
Donald Askew Roadley.
George Robinson.

Ernest Lawrence Robson.
Maurice Alva Rocheford.
David Wyndham Colenso Rodda.
Stuart Fletcher Russell.
Derek Ernest Sandall.
Cedric Sandell.
Ponniah Sanmugam Sanmuganathan
John Russell Edward Scammell.
Erle John Sherring.
Cecil Selvaduraibajah Sinnadurai
Thambiah Sivathasan.
John William Gage Sloan.
Eric John Small.
Stafford John Hallings Smith.
Stanley William Smith.
William Sommerville.
Charles Alan Southwell.
John Jeffrey Speed.
Dudley John Steel.
William John Steel.
John Stopforth.
Colin Edward Stopps.
William Evarts Streeten.
David John Such.
Jankie Nanan Supersad.
John Swale.
Ronald Clive Symes.
George Mowat Brown Taylor.
Ronald Bryce Taylor.
John Windsor Thomas.
William Tie.
Geoffrey Peter Tobin.
Alan Geoffrey Toft.
John Sankey Tolputt.
Colin Albin Edgar Treasure.
Rex Richards Vetharaniam.
Chellamutu Vinayagamoorthy.
Norman Wallis.
Don Padmatilleka Wanigasekara-Mohotti.
Terence Michael Wardle.
Malcolm Derek Waterfall.
Thomas Alan Watkiss.
Dennis Arthur Waylett.
Michael Webb.
Michael Hansford Webber.
Albert Thornton White.
Senarath de Silva Wijesundera.
Christopher Wiley.
Brian Wilkinson.
Cyril John Stephen Williams.
Trevor James Williams.
David Cameron Wilson.
Stanley Wilson.
Michael Roy Woodward.
Wong Cheuk Chi.
Gordon Ivor Young.

and had admitted as

Graduates

John Chadwick Adam (*Stud.I.C.E.*).
James Denis Addly, B.Sc. (*Edin.*), (*Stud.I.C.E.*).
Michael John Affleck (*Stud.I.C.E.*).
Kenneth Jordan Alderson, B.Sc. (*Durham*).
Charles David Allen, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Alexander Morgan Allison, B.Sc. (*Eng.*) (*Lond.*).
Kanagasabapathy Anandarajah, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Alexander David Anderson, B.Sc. (*Edin.*) (*Stud.I.C.E.*).
David Anderson (*Stud.I.C.E.*).
Kenneth Victor Andre, B.Sc. (*Witwatersrand*).
James Alastair Collingwood Andrews, B.Sc. (Eng.) (*Lond.*), (*Stud.I.C.E.*).
Robert Livingston Arnott (*Stud.I.C.E.*).
John Mervin Francis Averill, B.Sc. (*Wales*) (*Stud.I.C.E.*).
Roger John Axtell, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Basil Edward Baldrey, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Eric Hugh Ballard, B.Sc. (Eng.) (*Lond.*).
John Bertram Wallace Banks (*Stud.I.C.E.*).
Geoffrey Bannister, B.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
David Garston Barber, B.Sc. (Eng.) (*Lond.*).
John Barlow, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Francis Barnwell, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
Eric Baron (*Stud.I.C.E.*).
Stanley Herbert Barr (*Stud.I.C.E.*).
Eric Lionel Barron, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Ronald Francis Bartholomew, B.Sc. (Eng.) (*Lond.*), (*Stud.I.C.E.*).
Robin Maxwell Baynes (*Stud.I.C.E.*).
John Beattie (*Stud.I.C.E.*).
Jack William Beavington(*Stud.I.C.E.*).
Kenneth Oliver Bell, B.Sc. (*Leeds*).
Donovan Harry Bennett, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Geoffrey Curtis Bennett (*Stud.I.C.E.*).
Geoffrey Townsend Bennett, B.A. (*Cantab.*).

George Deryk Bent, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
Leslie Benthem, B.Sc. (Eng.) (*Lond.*).
William John Bevan (*Stud.I.C.E.*).
John Edwin Bignell, B.C.E. (*Melbourne*).
Ronald Macdonald Birse, B.Sc. (*Edin.*) (*Stud.I.C.E.*).
James Lowe Blackhall, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
Alan Morris Bloxsom, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
Jan Bobrowski, B.Sc. (Eng.) (*Lond.*).
William Derek Boxall, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
Ronald Denys Boyle, B.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
Peter Francis Bradbeer, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Donald Raymond Bradley, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*)
James Derek Bradley, B.Eng (*Liverpool*) (*Stud.I.C.E.*).
Harry Nigel Bratt, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
Peter Henry Webb Bray, B.Sc. (Eng.) (*Lond.*).
John Britton (*Stud.I.C.E.*).
William Edward Wilby Brook, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
Hugh Rusby Brooksbank, B.A. (*Cantab.*).
Cecil Allen Brown (*Stud.I.C.E.*).
Robert William Brown, B.Sc. (*Bristol*), (*Stud.I.C.E.*).
Dennis Michael Brunskill (*Stud. I.C.E.*).
Charles Gabriel Bryan, B.Sc. (*Glas.*).
Charles Trevor Ratcliffe Bulmer, B.Sc. (Eng.) (*Lond.*).
Peter Burhouse, B.A. (*Cantab.*).
William Spiers Burnside (*Stud.I.C.E.*).
Raymond Neville Burton.
Colin Herbert Button, B.E. (*New Zealand*).
John Charles Finlay Cameron (*Stud. I.C.E.*).
Malcolm Carmichael Campbell (*Stud. I.C.E.*).
Harold Ezekiel Caters (*Stud.I.C.E.*).
Alan Caunce, B.Eng. (*Liverpool*) (*Stud. I.C.E.*).
Donald James Causby, B.E. (*Adelaide*).
John Ashton Chippindale (*Stud.I.C.E.*).
Geoffrey Maurice Clarkson, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Basil Stanley Cockroft, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Thomas Charles John Cogle, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
David Colebrook, B.A. (*Cantab.*).
Godfrey Robert Coleman (*Stud.I.C.E.*).
Anthony Roy Compton, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
Ivan Llewellyn Connell, B.A., B.A.I. (*Dublin*).
David Brian Cook (*Stud.I.C.E.*).
James Cook, B.Eng. (*Liverpool*) (*Stud. I.C.E.*).
Michael George Cooper, B.A. (*Cantab.*).
Bernard Godbridge Cope, B.Sc. (Eng.) (*Lond.*).
Michael Donald Cope, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Ian Thornton Cowie (*Stud.I.C.E.*).
William Dougal Cowie, B.Sc. (*Nottingham*).
Roger Kendrick Cox, B.Sc. (*Birmingham*), (*Stud.I.C.E.*).
Arthur John Craig, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
Harry Howard Crann, Ph.D., B.Sc. (*Birmingham*) (*Stud.I.C.E.*).
Terence Alexander Creaney, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Trevor James Codrington Crocker, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Arthur Roy Cruttenden (*Stud.I.C.E.*).
William Scott Cullens, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
David Stewart Currie (*Stud.I.C.E.*).
Anthony Ralph Cusens, B.Sc. (Eng.) (*Lond.*).
John Richard Cuthbert.
Patrick Francis Daly, B.E. (*National*) (*Stud.I.C.E.*).
Edward Shepherd Darling, B.A. (*Cantab.*).
Kenneth Thomson Davidson, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
David Brinley Davies.
David Maurice Davies, B.Sc. (*Wales*) (*Stud.I.C.E.*).
Frank Edward James Davies, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Owen William Albert Daw, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Neville John Day.
Hendahewa Chandrawansa Dayatileka de Silva, B.Sc. (Eng.) (*Lond.*).
Ronald Colin Deacon, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Neville Teare Deakin, B.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
Noel Dean (*Stud.I.C.E.*).
Dennis Dearlove, B.Sc.(Eng.) (*Lond.*).
Thomas Keith Dellaway, B.E. (New *Zealand*).
Geoffrey Hargreaves Dencer, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
Dudley Dennington, B.Sc. (Eng.) (*Lond.*).
William Maxwell Dixon, B.A. (*Cantab.*).

George Gordon Dobson, B.Sc. (*Durham*).
Richard Dobson (*Stud.I.C.E.*).
William Dale Dodshon (*Stud.I.C.E.*).
George William Donaldson, B.Sc. (*Cape Town*).
Mark Ransom Dorey, B.Sc. (Eng.) (*Lond.*).
Geoffrey Colin Doyle (*Stud.I.C.E.*).
Eric Archer Driver.
Brian Godfrey Drummond, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Joseph Byrom Duffy, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Frederick Lenfestey Duquemin, B.Sc. (*Birmingham*).
Denis Nigel Warriner Earp, B.A. (*Cantab.*) (*Stud.I.C.E.*).
David William Wood Edwards, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Abel Rahman Ahmed El Agib.
William Denis Elders (*Stud.I.C.E.*).
Hubert Edward Elliott, B.Sc. (*Wales*), (*Stud.I.C.E.*).
John Edward Elliott, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*).
Iorwerth Tudor Ellis, B.Sc. (*Wales*) (*Stud.I.C.E.*).
Peter Craven Emes, B.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
Donald Lisle Emtage.
Henry Chanoch Erntroy, B.Sc.(Eng.) (*Lond.*) (*Stud.I.C.E.*).
Clifford John Evans, B.A. (*Cantab.*) (*Stud.I.C.E.*).
John Cecil Faber, B.A. (*Cantab.*) (*Stud.I.C.E.*).
John Ramsden Facer, B.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
Ronald McRobbie Faichney, B.Sc. (*Glas.*).
Michael Faragher, B.Eng. (*Liverpool*).
Ian Stuart Reid Farquharson, B.A. B.A.I. (*Dublin*).
Roger Richmond Farrant (*Stud.I.C.E.*).
John Brian Law Faulkner, B.Sc. (*Birmingham*) (*Stud.I.C.E.*).
Harold Fealdman, M.A. (*Cantab.*) (*Stud.I.C.E.*).
Peter John Fells (*Stud.I.C.E.*).
Stanley Graham Stuart Feneron, B.Sc. (Eng.) (*Lond*) (*Stud.I.C.E.*).
Donald McPhail Hall Ferguson, B.Sc. (*Glas.*).
Jesse Harold Fleck, B.Sc. (*Belfast*).
James Fletcher.
Walter Fokschaner, B.Sc. (Eng.) (*Lond.*).
Donald John Chisholm Forbes, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Raymond Denis Fox, M.A. (*Cantab.*).
Ian Whitehead Francey (*Stud.I.C.E.*).
Derek William Franklin, M.A. (*Cantab.*) (*Stud.I.C.E.*).
Henry William Friend (*Stud.I.C.E.*).
Allen William Fulton, B.M.E. (*Melbourne*).
James Anthony Gaffney, B.Sc. (Eng.) (*Lond.*), (*Stud.I.C.E.*).
Peter Kingsley Gardner, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Pauline Garmirian, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
James Alexander Geddes (*Stud.I.C.E.*).
David Gregory Gedge, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Alvin Brian George, B.Sc. (*Birmingham*) (*Stud.I.C.E.*).
Thanuvelil Koshy George, M.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
Thomas Clive Gillison (*Stud.I.C.E.*).
John Neville Gooch, B.Sc. (Eng.) (*Lond.*).
Charles Douglas Goode, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Arthur John Goss, B.Sc. (*Wales*) (*Stud.I.C.E.*).
Richard Ling Gouge, B.A. (*Cantab.*).
Robert Henry David Grace, B.Sc. (*St. Andrews*).
Victor Thomas Charles Graney.
Alexander Gray, B.Sc. (*Aberdeen*) (*Stud.I.C.E.*).
Ronald Greatrix.
Maurice Greenbaum, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Douglas George Greenwood, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Malcolm Spencer Gregory, B.E. (*Tasmania*).
John Keith Gregson, B.Sc. (*Nottingham*) (*Stud.I.C.E.*).
John McEwan Grubb (*Stud.I.C.E.*).
Arnold Walker Gunstone, B.Eng. (*Liverpool*).
Albert Edward Gurney, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
Roland Hall (*Stud.I.C.E.*).
William Roy Hall.
David Leighton Hanson, B.Sc. (*Wales*) (*Stud.I.C.E.*).
Alan Robert Hardy (*Stud.I.C.E.*).
Barry Edleston Hardy (*Stud.I.C.E.*).
Walter Robert Hare, B.Sc (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Geoffrey Garth Shortland Harper (*Stud.I.C.E.*).
Michael Coppinger Harries, B.A. (*Cantab.*).
David John Harris, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Brian Harrison (*Stud.I.C.E.*).

DONALD ANTHONY HARVEY (*Stud.I.C.E.*).
ALEXANDER THOMAS HAWKINS, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
MICHAEL JAMES HAWKINS, B.Sc. (*Belfast*).
KENNETH HAROLD HEAD, B.A. (*Cantab.*) (*Stud.I.C.E.*).
THOMAS MICHAEL HEATON, B.Sc. (Eng.) (*Lond.*).
JAMES IAN FORBES HENDERSON, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
LESLIE NATHAN HENDERSON(*Stud.I.C.E.*)
SIDNEY JAMES HERBAGE (*Stud.I.C.E.*).
RONALD JOHN HERD (*Stud.I.C.E.*).
GORDON DEREK HILL (*Stud.I.C.E.*).
NORMAN HILTON (*Stud.I.C.E.*).
JOHN MICHAEL HINCHLIFFE (*Stud.I.C.E.*).
HAROLD VERNON HIRD, B.A. (*Cantab.*).
STEPHEN LEE HOBDEN, B.Sc. (Eng.) (*Lond.*).
JAMES BENTLEY HODGSON, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
JOHN HENRY HOGG, B.Sc. (*Edin.*) (*Stud. I.C.E.*).
GRAHAM THOMAS HOLDING (*Stud.I.C.E.*).
ERIC WILLIAM HOLMES (*Stud.I.C.E.*).
PETER HOLMES (*Stud.I.C.E.*).
CLIFFORD FREDERICK HOLT (*Stud.I.C.E.*).
WILLIAM KEITH WYNN HORSFIELD, B.Sc. (*Manchester*).
JOHN FREDERICK HOUNSLOW, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
THOMAS RONALD HOUSTON, B.Sc. (*Belfast*).
JOHN HENRY DEWSE HOWLETT (*Stud. I.C.E.*).
NORMAN HOYLE, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*).
HAROLD WILLIAM CHARLES HUBBARD, B.Sc. Tech. (*Manchester*).
FREDERICK HESKETH HUGHES, B.Sc. (*Nottingham*) (*Stud.I.C.E.*).
WILLIAM BARRY HUGO, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
JOHN OLIVER HULBERT (*Stud.I.C.E.*).
JAMES ANTHONY HUMPHREYES, B.A. (*Cantab.*).
ROBERT HUNTER (*Stud.I.C.E.*).
GEOFFREY HUTCHISON, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
KENNETH HUTTON, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
JOHN ANTONY IRVING (*Stud.I.C.E.*).
JAMES MARTIN JACKSON, B.Sc. (*Belfast*) (*Stud.I.C.E.*).
ROBERT TYERMAN JACKSON (*Stud.I.C.E.*).
ANTHONY JAMES (*Stud.I.C.E.*).
DAVID TRAFFORD JAMES (*Stud.I.C.E.*).
DENNIS FREDERICK JAMES (*Stud.I.C.E.*).
KENNETH JOHN JAMES (*Stud.I.C.E.*).
ROBERT KENNETH JAMES (*Stud.I.C.E.*).
DAVID ARTHUR JARMAN, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
MICHAEL HENRY JEFFREY, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
ERIC GRAELY JENKINS, B.Sc. (*Wales*) (*Stud.I.C.E.*).
GRAHAM LLEWELLYN JOHN, B.Sc. (*Wales*) (*Stud.I.C.E.*).
KENNETH CHARLES JOHNSON (*Stud. I.C.E.*).
ARNOLD JONES (*Stud.I.C.E.*).
DAVID GEOFFREY JONES, B.Sc. (*Wales*).
KENNETH WILLIAM JONES, B.Sc. (*Wales*).
ROBERT ARTHUR JONES (*Stud.I.C.E.*).
ROBERT WALTER JONES, B.Sc. (Eng.) (*Lond.*).
THOMAS ANEURIN RHYS JONES (*Stud. I.C.E.*).
THOMAS DAVID EMYR JONES, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
WILLIAM KEITH EHRET JONES (*Stud. I.C.E*).
WILLIAM REES JONES, B.Sc. (*Wales*).
ALAN JOYNSON, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*).
JOHN ARTHUR JUDGE, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
MICHAEL DESMOND KAVANAGH, B.Sc. (Eng.) (*Lond.*) (*Stud. I.C.E.*).
JOHN MARSHALL KAY (*Stud.I.C.E.*).
KLAUS ADOLF KAYE, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
BERNARD FRANK KEARSEY.
THOMAS BERTRAM KEEVILL, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
GEORGE KEMP, B.Sc. (*Birmingham*).
BRIAN EDWARD KENDALL, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
ROBERT KEWELL (*Stud.I.C.E.*).
LEONARD RISING KIDMAN, B.Sc. (*Cape Town*).
DEREK KINGSTON, B.Sc. (*Leeds*) (*Stud. I.C.E.*).
WILLIAM THOMAS KIRK, B.Eng. (*Liverpool*).
JAMES AFFLECK KIRKPATRICK, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
ANTHONY CHARLES KRARUP, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
THOMAS LANGE, B.Sc. (*Cape Town*).
VICTOR ANTHONY EXELL LAWLEY, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
ALAN ALBERT LAWRENCE (*Stud.I.C.E.*).
HENRY JOHN LAWRENCE (*Stud.I.C.E.*).
PETER LAYFIELD (*Stud.I.C.E.*)
FREDERICK EDWIN LEAFE (*Stud.I.C.E.*).
ALAN CLIVE NODES LELLO (*Stud.I.C.E.*).
JOHN ALFRED LE PRIVERT, B.Sc. (*Aberdeen*).
GEOFFREY HESKETH LEWIS, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
RAYMOND WALLACE LEWIS, B.Sc.(*Wales*).
ROBERT BRETTON LEYLAND, B.Sc. (*Manchester*), (*Stud.I.C.E.*).

Samuel George David Lidstone, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Stanley Lilley, B.Sc. (*Belfast*) (*Stud. I.C.E.*).
Julian Colville Lindsay, B.Sc. (*St Andrews*).
Andrew Litten (*Stud.I.C.E.*).
John Denys Littler, B.Sc. (*Manchester*).
Ronald James Livesey (*Stud.I.C.E.*).
Geoffrey Wray Longley, B.Sc. (*Cape Town*).
Donald James Longman, B.Sc. (Eng.) (*Lond.*).
Peter Lownds, B.Sc. (*Manchester*) (*Stud. I.C.E.*).
Bryan Senior Lucas (*Stud.I.C.E.*).
Archibald Hugh McCallum, B.Sc. (*Glas.*).
Roy McCarthy, B.Eng. (*Liverpool*).
John Donald McCaughey, B.A. (*Cantab.*).
Robert Hugh MacDonald, B.Sc. (*Belfast*).
Alfred Stanley McDermott, M.A. (*Cantab.*).
Gordon Muir Macfarlane (*Stud.I.C.E.*).
John Welsh McGarrity (*Stud.I.C.E.*).
John Philip McGill, B.Sc. (*Belfast*).
Andrew Jamieson MacInnes.
George Mack, B.Sc. (*Manchester*) (*Stud. I.C.E.*).
Kenneth Mackenzie, B.Sc. (*Edin.*) (*Stud.I.C.E.*).
Duncan Cameron Maclean, B.Sc. (*Glas.*).
Garnett McLean, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
William Purves McLeish, B.Sc. (*Edin.*).
Samuel James McMurray, B.Sc. (*Belfast*) (*Stud.I.C.E.*).
Michael Martin McNamara, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Colin Brand Macrae (*Stud.I.C.E.*).
David Christopher Maddocks, B.A. (*Cantab.*).
William Joseph Maggs (*Stud.I.C.E.*).
Thomas Francis Magner B.E. (*National*) (*Stud.I.C.E.*).
Geoffrey Russell Magson, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Malcolm Robert Mair, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Frank Thomas Mann, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Frederick Walter Thomas James Mapstone (*Stud.I.C.E.*).
David Francois Menmuir Marais, B.Sc. (*Cape Town*) (*Stud.I.C.E.*).
Geoffrey Philip Martin, B.Sc. (*Birmingham*) (*Stud.I.C.E.*).
Roy Herbert Mather, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
George Douglas Matthew, B.Sc. (*Aberdeen*) (*Stud.I.C.E.*).
Michael Arthur May (*Stud.I.C.E.*).
William Thomas Michael Mee, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Maurice William Milburn, B.Sc. (*Durham*) (*Stud.I.C.E.*).
Andrew Todd Millar, B.Sc. (*Edin.*) (*Stud.I.C.E.*).
Lauchlan Millar (*Stud.I.C.E.*).
William Donald Millar, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Alexander McKay Henderson Miller, B.Sc. (*Glas.*).
Dudley John Mills (*Stud.I.C.E.*).
David Mitchell.
John Cedric Mobbs, B.Sc. (Eng.) (*Lond*) (*Stud.I.C.E.*).
Bertram Denipitiya Mohandiramge, B.Sc. (Eng.) (*Lond.*).
John Kelland Morgan, B.Sc. (*Wales*), (*Stud.I.C.E.*).
Ian Stanley Muir, B.Sc. (*Durham*) (*Stud.I.C.E.*).
Hugh Duncan Blue Murray (*Stud. I.C.E.*).
William Tyrrell Murray, B.Sc. (*Durham*).
Malcolm Augustus Napier, B.Sc. (*Wales*), (*Stud.I.C.E.*).
John Clive Nettleton, B.E. (*New Zealand*).
Richard Frederick Newton (*Stud. I.C.E.*).
Kenneth Leslie Henry Niall, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Thomas Parker Nicholl, B.A. (*Cantab.*).
Thomas Hedley Nicholson, B.Sc. (*Durham*) (*Stud. I.C.E.*).
Alan Monro Nicol, B.A. (*Cantab.*).
Mayer Nispel, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*).
Patrick Timothy O'Connell, B.E. (*National*) (*Stud.I.C.E.*).
Terence O'Connor, B.Eng. (*Sheffield*) (*Stud.I.C.E.*).
Kenneth O'Farrell (*Stud.I.C.E.*).
Norman Arthur Oldham.
Peter Russell Olliver, B.Sc. (Eng.) (*Lond.*).
Derek Ormerod, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*).
Kenneth Alwyn Owens, B.Sc. Tech. (*Manchester*).
Roger Earle Padwick, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
David Michael Paget, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Roualeyn Edwin Gordon Parker, B.Sc. (*Cape Town*).
Maurice Alwyn Parsons (*Stud. I.C.E.*).

Eric Francis Pascall, B.Sc. (Eng.) (*Lond.*).
Colin Alexander Paterson, B.A. (*Cantab.*).
Ian Hamilton Paxton, M.A. (*Cantab.*) (*Stud.I.C.E.*).
Victor John Payne (*Stud.I.C.E.*).
George Leonard Pell, B.Sc. (Eng.) (*Lond.*).
Duncan John Pennington, B.Sc. (Eng.) (*Lond.*).
Joseph Douglas Perret, B.Sc. (*Birmingham*) (*Stud.I.C.E.*).
Mark Pharaoh, B.Sc. (*Manches er*).
Michael Harris Phelps (*Stud.I.C.E.*).
John Morgan Philip, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
John William Phillips, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Kenneth Austin Phillips (*Stud.I.C.E.*).
David Peter Pickup, B.Sc. (*Durham*) (*Stud.I.C.E.*).
Norman William Pidgeon (*Stud.I.C.E.*).
James Hugh Pilling, B.Sc.Tech. (*Manchester*) (*Stud.I.C.E.*).
Derek Charles Pool (*Stud.I.C.E.*).
James Fraser Pool, B.Sc. (*Witwatersrand*), (*Stud.I.C.E.*).
Leslie Frederick Poole (*Stud.I.C.E.*).
Douglas Samuel Potter, B.Sc. (*Wales*).
John Hordley Potter, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*).
Alan Joseph Pownall, M.A. (*Cantab.*) (*Stud.I.C.E.*).
Arthur Robert Powell (*Stud.I.C.E.*).
William John Prescott-Decie, B.A. (*Cantab.*).
William Alan Price, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Gordon Alan Pritchard (*Stud.I.C.E.*).
Frank Slingsby Proctor, B.Eng. (*Sheffield*) (*Stud.I.C.E.*).
Kathiresu Appathurai Rasarathinam, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Gordon Stanley Rattley, B.Sc. (Eng.) (*Lond.*).
Edward Arthur Venables Reading, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Douglas Enderby Refell, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Denis Reily, B.A. (*Cantab.*).
Robert William Rennison, B.Sc. (*Durham*) (*Stud.I.C.E.*).
Stephen Revesz, M.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Brian Rhodes (*Stud.I.C.E.*).
Eric Geoffrey Riddiough (*Stud.I.C.E.*).
Allan Stewart Riley, B.A. (*Cantab.*).
Richard Woodburne Riley, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Alistair George Baldwin Ritchie, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
Robert Whitelaw Ritchie (*Stud. I.C.E.*).
William Gordon Neil Roach, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Graham John Roberts (*Stud.I.C.E.*).
John Fawcett Roberts, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
John Robertson (*Stud.I.C.E.*).
Alfred Robinson, B.Sc. (Eng.) (*Lond.*).
Barry Norman Robinson, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
Derek Hugh Robinson, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
George Leslie Robinson, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Walter Robinson, B.A., B.A.I. (*Dublin*)
George Wyndham Howard Rodel, B.Sc. (*Natal*).
Gordon Michael Rose (*Stud.I.C.E.*).
John Alan Rostern, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
Roy Ernest Rowe, B.A. (*Cantab.*).
Robert Dennis Runnacles (*Stud. I.C.E.*).
William Roger John Sammons (*Stud. I.C.E.*).
James Gordon Samson (*Stud.I.C.E.*).
Ronald Herbert Samuel, B.Eng. (*Liverpool*) (*Stud.I.C.E.*).
David Harrison Scholes, B.A. (*Cantab.*) (*Stud.I.C.E.*).
David Alexander Noel Scott, B.Sc. (*Cape Town*) (*Stud.I.C.E.*).
Jeffrey Scott, B.Eng. (*Sheffield*).
Ronald Edward Sellers, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Barry Wilson Shacklock, B.Sc. (*Durham*) (*Stud.I.C.E.*).
John Michael Shadbolt, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
William Thomas Duncan Shaddick, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Robert Graham Sharp, B.Sc. (Eng.) (*Lond.*).
Jack Bryan Shaw, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Philip Thomas Shaw, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
James McKenzie Shearer, B.Sc. (*St Andrews*) (*Stud.I.C.E.*).
Joseph Sheridan, B.Sc., Tech. (*Manchester*).
Derek Sherlock (*Stud.I.C.E.*).
Joseph Domnick Shinkwin, B.E. (*National*).
James Cleave Simmons, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Noel Edward Simons, B.Sc. (*Natal*).
Peter John Sims, B.Sc. (Eng.) (*Lond.*).
George Sloan, (*Stud.I.C.E.*).
Granville Barrie Smedley, B.Sc. Tech. (*Manchester*).

Cecil Letham Smith, B.Sc. (*Manchester*) (*Stud.I.C.E.*).
David Fleming Smith, B.Eng. (*Liverpool*).
Eric Smith (*Stud.I.C.E.*).
John Smith, B.Sc. (*Leeds*).
Roger Partridge Smith (*Stud.I.C.E.*)
William Andrew Smith, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
Stanley Herbert Somerville (*Stud. I.C.E.*).
Geoffrey Vincent Sparks, B.C.E. (*Melbourne*).
Alan Franklin Staig, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Harry Victor Stanton.
David Stephens, B.Eng. (*Sheffield*) (*Stud.I.C.E.*).
George Raymond Stephens (*Stud. I.C.E.*).
John Steventon (*Stud.I.C.E.*).
George Davidson Steward (*Stud. I.C.E.*).
Donald Stewart, B.Sc. Tech. (*Manchester*).
Eric Thompson Stewart, B.Sc. (*Belfast*) (*Stud.I.C.E.*).
John Coulter Stewart, B.Sc. (*Glas.*) (*Stud.I.C.E.*).
Neil William Stocks (*Stud.I.C.E.*).
Richard Lawson Stoker, B.A. (*Cantab.*).
Frank Leslie Hallam Straw, B.Sc. Tech. (*Manchester*) (*Stud.I.C.E.*)
Gordon John Street (*Stud.I.C.E.*).
Howard Fleming Sturrock, B.Sc. (*St Andrews*).
Kenneth James Surridge, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Peter Brian Swales, B.A. (*Cantab.*).
Ronald Swan, B.Eng. (*Sheffield*).
Alfred Grange Talbot, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Charles Wilfred Tate, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Bruce Maynard Taylor, B.Sc. (*Glas.*).
John Robson Taylor, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Leonard Edwin Taylor, B.Sc. (*Eng.*) (*Lond.*) (*Stud.I.C.E.*).
Philip Austin Taylor (*Stud.I.C.E.*).
Teoh Hua Tuan, B.Sc. (*Durham*).
Michael Rex Marriott Tetley, B.Sc. (*Witwatersrand*).
Alexander Graham Tevendale, B.Sc. (*St Andrews*).
David Howard Thomas, B.A. (*Oxon*).
Brian David Threlfall, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Peter Hugh Tinsley, B.A. (*Cantab.*) (*Stud.I.C.E.*).
John Ewart Todd (*Stud.I.C.E.*).
Geoffrey Peter Tobin, B.A. (*Cantab.*) (*Stud.I.C.E.*).
Robin John Tollast, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Richard Chambrey Townshend, B.A. (*Cantab.*).
Robert Wilson Trainor, B.Sc. (*Belfast*) (*Stud.I.C.E.*).
Kenneth Stewart Trollop (*Stud. I.C.E.*).
Clifford Haig Turner (*Stud.I.C.E.*).
Donald Malcolm Conway Turner, B.Sc. (Eng.) (*Lond.*).
David Richard Tyler, B.Sc. (*Nottingham*) (*Stud.I.C.E.*).
Alexander Ernst Utas, B.Sc. (Eng.) (*Lond.*).
Anthony John Vail, B.Sc. (Eng). (*Lond.*).
Michael Henry Godwin Vicker (*Stud. I.C.E.*).
Dennis Vickers (*Stud.I.C.E.*).
Thomas Barry Wade, B.Eng. (*Sheffield*) (*Stud.I.C.E.*).
Donald Cameron Grimshaw Walker (*Stud.I.C.E.*).
Robert Cope Walker, B.Eng. (*Sheffield*) (*Stud.I.C.E.*).
William Robin Walker, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Alexander Wallace, B.Sc. (*Edin.*) (*Stud.I.C.E.*).
John Alan Wallwork, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Sidney George Walters.
John Robert James Walters (*Stud. I.C.E.*).
Martin John Peter Warham, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Alan George Waters, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Richard Empson Waters, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Howard John Mansel Watkins, B.Sc. (*Wales*).
Donald Ernest Watts.
Thomas William Weddell, B.Sc. (*Durham*) (*Stud.I.C.E.*).
Leslie Bernard Wellings, B.Sc. (Eng.) (*Lond.*).
Kenneth James Wells, B.Sc. (*Birmingham*) (*Stud.I.C.E.*).
Arthur William West, B.A., B.A.I. (*Dublin*).
Kenneth James White, B.Sc. (*Leeds*) (*Stud.I.C.E.*).
Michael Allan Wilcox, B.Sc. (*Leeds*).
David Maxwell Wilding, B.A., B.A.I. (*Dublin*).
Brian Wilkinson, B.Eng. (*Sheffield*) (*Stud.I.C.E.*).

David Allan Williams, B.Eng. (*Sheffield*).
Peter Norman Williams (*Stud.I.C.E.*).
Maurice Willis Creighton Williams, B.A., B.A.I. (*Dublin*).
Robert Idwal Tudor Williams, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
Douglas Albert Wills (*Stud.I.C.E.*).
Christopher Cairns Wilson, B.Sc. (*Edin.*) (*Stud.I.C.E.*).
George Edward Brian Wilson, B.Sc. (*Cantab.*) (*Stud.I.C.E.*).
Terence Charles Wilson, B.Sc. (Eng.) (*Lond.*).
Godwin Felix Patuwatha Withana, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*)
Charles David Wood, B.Eng. (*Liverpool*).
John Frederick Dilworth Wood (*Stud.I.C.E.*).
Norman Francis Wood, B.A. (*Cantab.*).
Anthony John Woodford, B.Sc. (Eng.) (*Lond.* (*Stud.I.C.E.*).
Philip Michael Worthington, B.Sc. (Eng.) (*Lond.*), (*Stud.I.C.E.*).
Stanley Cempson Wright, B.Sc. (Eng.) (*Lond.*) (*Stud.I.C.E.*).
William John Young, B.Sc. (Eng.) (*Lond.*).
Isaac Maier Zelman, B.Sc. (*Manchester*).
Michael Zinn, B.A. (*Cantab.*).

The Secretary announced the awards which had been made by the Council for Papers presented during the Session 1951–52. Full details of all these awards are given on p. 39.

A number of the recipients were in attendance and the President made the following presentations :—

A Telford Gold Medal and Certificate to Dr Carlo Semenza ;
Certificates of the award of Telford Premiums to Messrs A. A. Fulton, R. H. MacDonald, and J. T. Calvert ;
Certificates of the award of a Crampton Prize to Messrs W. Storey Wilson and F. W. Sully ;
a James Forrest Medal and Certificate to Mr F. G. Johnson ; and an Institution Medal to Mr R. B. Sims.

The Retiring President said that it was his great pleasure and privilege to introduce to the Meeting the new President, although no introduction of Mr Cronin was in fact necessary. Mr Cronin, who had for many years with great distinction held the important position of Chief Engineer of the Metropolitan Water Board, had at the same time given most valuable and painstaking, service to the Council, to the Institution, and to the civil engineering profession, and had earned their deep gratitude, their admiration, and their affection. Mr Quartermaine welcomed him most heartily as the new President of the Institution, knowing full well with what honour and success he would lead the Institution, and wished him good fortune and happiness in the Chair.

He then requested the new President to take the Chair.

Mr Henry Francis Cronin, C.B.E., M.C., B.Sc., then took the Chair as President and called on Mr David M. Watson to move a resolution.

Mr David M. Watson, Vice-President, moved the following resolution:—

"That the members present at this Meeting desire, on behalf of themselves and others, to record their high appreciation of the services rendered to the Institution by Mr A. S. Quartermaine during his term of office as President."

Although Mr Quartermaine, he said, had slipped so easily from *the* Chair to *a* chair, the members would not want him to do so unnoticed. Mr Quartermaine was only human, and might well have some feeling of relief as he moved to the other chair, but it was perhaps very largely because he was so very human that he had been such a great success as a President and had made himself so popular.

It was true to say that Mr Quartermaine ought also to have feelings of pride and satisfaction in a job which had been done well. It was probable that the members of the Institution, and they alone, were in a position to give him that feeling, and there could be no doubt that they intended to do so.

It might be regarded as not quite fair, but Mr Watson confessed that he had looked up some of the words used by Mr Quartermaine in his Presidential Address a year ago, and found that in the opening paragraph of that Address he had said: " . . . I am very mindful of the responsible task which lies before me. Remembering the eminent engineers who have held this office, I enter upon my duties with pride and humility, and the earnest hope that I may be able to serve the members, the Institution, and the profession, in a manner worthy of your trust." There might be no very definite promise in that, but the present meeting was the court and the members present were the judge and jury who would decide that point, while Mr Watson—self-appointed, perhaps—was counsel for the defence. He was untrained, he was inexperienced, but he had not the slightest doubt about the verdict, because really there was no case for the prosecution at all.

Mr Watson had already referred to Mr Quartermaine's manner, which had, he felt sure, enabled him to do more satisfactorily and more expeditiously many things that would not have been quite so easy otherwise. The Members of the Council who had had the privilege of sitting on the Council under Mr Quartermaine knew better than most people the very wise counsel for which he had always been famed and the able way in which he had advanced the Institution's affairs. Mr Watson wondered if it was generally known how very hard Mr Quartermaine had worked for the Institution during his year of office. He had devoted nearly the whole of his time to that work, which he had carried on unremittingly; he had never spared himself, and he had never failed the Institution.

Mr Watson wished to give one illustration, which he felt would be quite

sufficient, of what Mr Quartermaine had done. He had recently completed a tour of the United States and Canada, undertaken on behalf of the members of the Institution. It had undoubtedly been a very arduous task, physically and mentally and, it might perhaps be added, gastronomically too! During that visit he had no doubt attended many banquets, but he had been present at one in particular where there were about a thousand guests, amongst whom were people such as ex-President Hoover. Mr Quartermaine was asked—that in itself was a high honour—if he would address the gathering on behalf of the profession of engineers of the world, and he did so. It would be known to most of the members present that it was not the custom in the United States to drink toasts, and that Americans were not easily moved. They apparently remained seated after an after-dinner address and merely applauded; but when Mr Quartermaine finished his remarks all the guests accorded him the signal honour of rising to their feet spontaneously and applauding him. That illustration was typical of the way in which Mr Quartermaine had carried the professional flag during his year of office.

Mr Watson then invited the members present, the jury, to bring in their verdict that Mr Quartermaine had most markedly proved to be "worthy of their trust."

Mr R. W. Mountain, who seconded the motion, observed that in doing so there was very little that he could add to the admirable words of Mr Watson. Having observed Mr Quartermaine during his year of office as President from the position of a Member of Council and a member of the Institution, Mr Mountain wished to pay a modest tribute to Mr Quartermaine's kindness and tolerance during all the meetings of the Institution and of the Council. That kindness and tolerance must have permeated right through the Institution during his year of office.

Mr Quartermaine, in acknowledging the vote of thanks, said that Mr Watson and Mr Mountain had expressed sentiments and made remarks which he appreciated most fully. He accepted their sincerity, though he could not accept all the credit that they sought to give him. If the ship had been kept on a level keel and had even made a little headway during the past year, it had been due to the efforts of the Members of Council, backed by the Secretary and all the hard-working and helpful members of the Institution staff. It was very pleasing to him to record that, although there had been much work at times, he had been very happy during the period of his office, and that had been due to the unstinted support and undoubted ability of the Council. To all the Members of Council, to other members of the Institution who had freely given of their time on Committees and in other work for the Institution, to Mr Graham Clark, and to all the Institution staff he tendered his sincerest thanks. He looked forward with confidence to the continued and increasing progress of the affairs of the Institution.

The President than delivered the following Address.

PRESIDENTIAL ADDRESS OF

Henry Francis Cronin, C.B.E., M.C., B.Sc.(Eng.)
President, 1952-53

In electing me your President you have conferred upon me a very great honour and one which I esteem most highly. I do, indeed, sincerely thank you for this, and I will use my best endeavours to fulfil the duties of this high office to the utmost of my ability, and I hope to your satisfaction.

I must now devote my attention to my first task, and that is, the Presidential Address. In this, unlike many of my predecessors, I have no cause to complain of lack of material, my only fear being that neither my pen nor my ability will be able to do justice to the subject which I have chosen.

In a few weeks' time there will occur the 50th anniversary of the passing of the Act which authorized the formation of the Metropolitan Water Board, and since I am proud to have spent over 32 very happy years in the employment of that Undertaking, it is natural to choose the water supply to London as the theme of this Address.

The Board is a public Authority composed of sixty-six Members, elected by the various Local Authorities and certain other bodies. When it came into being it acquired by purchase the Undertakings of the eight Metropolitan Water Companies, as well as those of the Urban District Councils of Enfield and Tottenham. At the present time the Board have 6½ million consumers, residing in an area of approximately 540 square miles. These and the industries in which they are employed required in 1951–52 an average daily supply of 316 million gallons. Added to this were bulk supplies of 6 million gallons per day, so that the total average daily demand was 322 m.g.d. Of this, 219 m.g.d. were derived from the Thames, 54 m.g.d. from the Lee, and the remaining 49 m.g.d. from underground sources.

The principal works dealing with Thames water lie between Staines and Surbiton, although there are still filtration and pumping stations nearer to London, at Barnes, Barn Elms, and Kew.

In the Lee Valley, the works stretch from Hertford to Hackney. The positions of the various works and places referred to in this Address (with the exception of Amwell End, Amwell Hill, and Cheshunt) are shown in Fig. 1, Plate 1.

Nearly two million persons live in the catchment area of the Thames above the intakes, whilst in that of the Lee the number is about 280,000. In consequence, all the river water is polluted or is liable to pollution and the treatment consists of retention in storage reservoirs, filtration, and

chlorination. About three-quarters of the well water is sufficently pure to be pumped direct into supply after chlorination, but the remainder is delivered into the New River and, mixed with River Lee water, is filtered at Hornsey and Stoke Newington.

The whole of the supply to London is dependent on pumping and the magnitude of this operation will be appreciated when it is realized that from the Thames works alone about 1 million tons of water on a normal day, rising to 1⅓ million tons on a peak day, have to be pumped into London.

The Board is one of the largest Water Undertakings in the world, supplying a population of 6½ million persons—compared with 8 million persons supplied by New York. Owing, however, to the greater use of water in the United States the consumption in New York is about 870 m.g.d. whilst the City of Chicago with 3·6 million consumers requires no less than 734 m.g.d. as against 316 m.g.d. for the Metropolitan Water Board Area. All these figures are in Imperial gallons.

Mere size, however, is no criterion of performance and it is upon the latter that a Water Undertaking is judged. So far as meeting the demands of the consumer is concerned, the Board, in spite of difficulties due to wars and economic causes, has stood the test, but on account of the inability to construct more reservoirs, the future gives rise to some anxiety.

With regard to the purity of the supply, I cannot do better than to quote from the Government White Paper of 1944 entitled "A National Water Policy," in which it is stated :—

"Not so many years ago it was thought in responsible quarters that London would have to abandon the use of the Thames and the Lee, but today 90% of London's water—bacteriologically one of the purest in the world—comes from these two rivers."

The process of storing, purifying, and distributing the London water has sprung from small beginnings and has been built up slowly over the centuries. I therefore propose to take you back to the reign of Queen Anne and to ask you to accompany me on a brief excursion through part of the history and development of the pumped supply to London, not forgetting the names of some of the many engineers who laid the foundations of the Undertaking which the people of London possess today.

York Buildings Waterworks

In or about the year 1713 an important event took place, namely, the erection of the first steam-driven pumping engine in London. This was at the lower end of Villiers Street, at the York Buildings Waterworks, which were incorporated in the year 1675. The engine was a Savery engine, which has its modern counterpart in the Pulsometer pump. Very little is known about it, but it was not a success because the steam consumption was heavy and it was taken out of use some time before 1727.

Since the steam pressure is believed to have been of the order of 100 lb. per square inch, it may be surmised that considerable trouble was experienced with the boiler. However, the York Buildings Company were not daunted and in 1726 they erected another steam engine, this being the first Newcomen waterworks pumping engine in Great Britain. This also was unsuccessful but the Company persevered and in about 1752 they installed a second Newcomen engine. This apparently worked well and it was later followed by a third, after which the Company seems to have carried on their pumping arrangements satisfactorily until financial troubles overtook them and they were amalgamated in 1818 with the New River Company, the oldest of the eight London Water Companies, whose history formed part of the Presidential Address of Sir Jonathan Davidson in 1948.[1]

The Formation of the Metropolitan Water Companies

In 1723, the second of the large Water Companies was formed, namely, the Chelsea Company, which retained its name and identity for 180 years. The Company constructed an intake from the Thames at a point just east of Grosvenor Road Railway Bridge, and was followed some 60 years later, in 1785, by the Lambeth Water Company, which acquired land immediately downstream of Hungerford Bridge, on the site of the Royal Festival Hall, and pumped water to its consumers in the vicinity.

In the early years of the nineteenth century four more of the Water Companies were established, these being the West Middlesex in 1806, with works at Hammersmith and later, in 1830, at Barnes; the East London in 1807; the Kent Waterworks, which took over the River Ravensbourne works at Deptford, in 1809; and, in 1811, the Grand Junction Company.

In the meantime, steam pumps had continued to make progress. In 1778, a Watt engine, with its separate condenser, was erected for the first time at a London waterworks in Shadwell, and thereafter a considerable number of these engines were built, some of which had very long lives. For example, a Boulton and Watt engine, installed at Deptford in 1812 and altered in 1845, was not taken out of use until 1926, and before it was broken up parts of the parallel motion were incorporated in the handrailing of the new Kempton Park engine house. Two other Watt engines were supplied to the Grand Junction Company at their Chelsea works in 1820. Subsequently, in 1840–43, after the Company had moved their intake to Brentford (Kew Bridge) these engines were re-erected there and worked until 1946. In 1846–48, they were rebuilt as Cornish engines and one of them is now preserved at Kew Bridge works, together with a 90-inch and a 100-inch Cornish engine, a Cornish Bull engine, and a converted Maudslay Beam, to form a museum of old pumping plant.

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[1] J. Instn Civ. Engrs, vol 31, p. 1 (Nov. 1948).

Early Select Committees and Royal Commissions

In granting statutory powers to the various Companies, Parliament had encouraged competition by allowing their areas of supply to overlap. After a time the Companies discovered that this policy did not pay and so in about the year 1815 certain of them entered into mutual agreements by which they undertook to refrain from competition where they had concurrent rights of supply. By this means each company created a monopoly in their own area and it was not long before the water charges, which had been too greatly depressed during the period of competition, were increased. This and the poor quality of the water supplied gave rise to complaints, and in 1821 there commenced the period during which a series of Inquiries by Select Committees of each and both Houses took place, four Royal Commissions were held, legislation was enforced on the Companies, and efforts were made to abolish them, all of which lasted until the beginning of this century, when upon the recommendation of Lord Llandaff's Royal Commission the Government introduced the Bill for the establishment of the Metropolitan Water Board.

The first Parliamentary Committee, appointed in 1821, was interested mainly in charges, but since nothing resulted from its labours, the water consumers were not satisfied and, as a result of petitions presented in 1827 alleging, *inter alia*, " that the water supplied by the Grand Junction Company to more than 7,000 families had been pronounced by professional men of the first eminence to be a filthy fluid, loaded with decayed vegetable and other substances equally deleterious to health and unfit for domestic consumption," Parliament set up the first Royal Commission " to enquire into the state of the water supply of the Metropolis."

The members of this Commission were William Thomas Brande, a well-known chemist, Dr P. M. Roget (the author of Roget's Thesaurus). and Thomas Telford, the first President of this Institution. The Commission reported in 1828 and found that " the present state of the supply of water to the Metropolis is susceptible of and requires improvement . . . many of the complaints . . . are well founded and it ought to be derived from other sources than those now resorted to."

Again no action was taken, but in 1828 a Select Committee of the House of Commons recommended that Mr Telford should be " instructed to report a practicable and efficacious plan for supplying the whole of the Metropolis with pure and wholesome water." This recommendation was adopted and on 17th February, 1834 (the year of his death), Telford presented his report, recommending that water for the supply of the north side of London should be obtained from the River Verulam, near Watford, and for the south side, from the River Wandle at Beddington, at a total estimated cost of nearly £2,000,000.

Telford's report was referred to another Select Committee but nothing more was done and the results of a House of Lords Committee of 1840,

which appeared chiefly to concern itself with an alleged illicit supply obtained from the New River Company by—of all persons—a milkman, were equally ineffective.

The time, however, was fast approaching when Parliament was to enact general legislation dealing with matters of health. In 1847, the Waterworks Clauses Act was passed and this was followed in 1848 by the first Public Health Act. The London Water Companies did not escape attention and in 1852 the Government introduced a Bill which, passing into law, exercised a profound and far-reaching influence on the water supply to the Metropolis. Before dealing with the provisions of this Act it is perhaps as well to say something about the events which led up to it.

Location of Intakes and Treatment of Water in 1850

Although the water in the Thames was in a bad state in the earlier part of the century and deteriorated as London expanded, it became very much worse after it had become permissive, and subsequently, in 1847, compulsory, to drain houses into the sewers, and as more and more cesspools were abolished. In the 1840's the intakes of the Companies were in the tidal reaches of the river, the lowest downstream being an emergency intake of the New River Company at Broken Wharf in the City. It is true that this was rarely used, but when it was open the Thames water was pumped directly into supply through a 33-inch main which connected to the distribution system in Cheapside. The normal sources of supply of this Company were Chadwell Spring, the River Lee, and a few wells sunk alongside the New River. No filtration was employed but the water was allowed to settle in reservoirs and ponds at Stoke Newington and at New River Head in Clerkenwell.

A little higher up, but on the south side of the river on the site of the Royal Festival Hall was the intake of the Lambeth Company, from which water was pumped to reservoirs at Brixton and Streatham, being passed through what is described as a vertical gravel filter at the former. The water in the river at this intake had become so bad that James Simpson, a Past President of this Institution, who was the Engineer to the Company —as well as to the Chelsea Company—had advised the Directors to move the intake to Ditton, and in 1848 powers were obtained for this to be done.

The next two intakes were those of the Chelsea and the Southwark and Vauxhall Companies, which were nearly opposite each other. At that time the Chelsea works were still on the original site —now occupied by the carriage sidings of British Railways (Southern Region)—on which James Simpson undertook his historic experiments in filtration in 1827 and built the first slow sand filter in London. In the 1840's all the water supplied by this Company was subject to settlement and to filtration.

The Southwark and Vauxhall Company was the last of the large Water Companies, being formed by an amalgamation of the Southwark and the

Vauxhall Companies. The new Company built sedimentation reservoirs and filter beds at Battersea on land purchased by the Southwark Company in 1839, and which is now the site of the Power Station.

Nearly 6 miles further up the river was the intake of the West Middlesex Company at Barnes, where the water was passed through sedimentation reservoirs but was not filtered before being pumped into supply from their works at Hammersmith.

The Grand Junction Company's first intake on the Thames was constructed in 1820 at Chelsea, at the mouth of the Ranelagh sewer, but on account of bitter complaints of the quality of the water, this being the subject of the famous pamphlet entitled, "The Dolphin," the works were moved in 1835–38 to Brentford, just upstream of Kew Bridge, and from that time onwards all the water supplied by the Company was abstracted at this point and passed through settling reservoirs. The first filter bed to be constructed here was completed in 1845.

In the Lee Valley, the East London Waterworks Company dates from 1807 when they absorbed the Shadwell and the West Ham Waterworks. The new Company built works at Old Ford and there abstracted water from the River Lee, but in 1829 they moved the intake to Lee Bridge where they had purchased the Hackney Waterworks. It was at Old Ford in 1838 that Thomas Wicksteed, M.I.C.E., the then Engineer to the Company, introduced the Cornish engine to London and at these works his first Cornish engine performed on trial more than double the duty of the existing Boulton and Watt engines.

Eventually, more than fifty engines of this type, including Cornish Bull engines, were erected in London, and at many of these pumping stations the standpipes, whether encased in brickwork or not, formed conspicuous features of the landscape.

The eighth Metropolitan Water Company was the Kent Waterworks Company, which obtained its water from the River Ravensbourne about a mile above its junction with the Thames at Deptford Creek. The

TABLE I

Company	Total number of tenements	Average daily supply : m.g.d.
New River	83,206	15·5
East London	56,673	9·0
Southwark and Vauxhall	34,864	6·0
West Middlesex	24,480	3·3
Lambeth	23,396	3·1
Chelsea	20,996	3·9
Grand Junction	14,058	3·5
Kent	9,632	1·1
Total	267,305	45·4

Company came into being in 1809 and the water first supplied from Deptford was subject to settlement only, but filter beds were completed at these works in 1844 and 1849.

Thus, in or about 1850, three of the Companies did not filter their water at all, and the process as applied by at least one other Company was of doubtful efficacy.

To give an idea of the amount of water supplied, the figures shown in Table 1 are taken from returns made in 1848 and 1849.

In addition, the Hampstead Company (which was acquired by the New River Company in 1859) supplied 4,490 tenements, with an average quantity of 0·4 m.g.d.

Report of General Board of Health, 1850

In 1847, a Royal Commission was appointed to inquire into the measures requisite for the improvement of the health of the Metropolis, with particular reference to drainage, street cleansing, paving, the removal of refuse, and the better supply of water. The cholera outbreak of 1848 diverted their attention from water supply and this was delegated to the General Board of Health, a body which had been set up under the provisions of the 1848 Public Health Act.

The Board consisted of the Earl of Carlisle, Lord Ashley (afterwards the Seventh Earl of Shaftesbury), Edwin Chadwick, the great sanitary reformer, and Dr Southwood Smith, and in 1850 they presented a voluminous report of 350 pages containing over 120,000 words and concluding with 63 findings.

Briefly, the Board considered that the London water supply was inferior to that of other towns, principally on account of its hardness. They condemned the intermittent supply and drew attention to the great waste of water which it occasioned. Further, they recommended the abandonment of the Thames as a source of supply and its substitution by water to be obtained from the Greensand on the Surrey and Hampshire borders. The report also dealt with drainage and the Board recommended that the water supply and drainage of the Metropolis should be placed under the control of one and the same body.

With regard to cholera, this was not attributed so much to the water supplied by the Companies as to the inefficient service which they rendered, resulting in the poorer classes seeking and obtaining water from polluted ditches, sewers, and wells, the latter source also being used by the well-to-do as evidenced by Dr Snow's classic research on the epidemic caused by the use of water from the Broad Street Well in Soho.

Another alleged disadvantage of the inferiority of the water supplied by the Companies was that "a large proportion of the population is rendered averse to the daily use of water as a beverage and is inclined and almost forced to the use of fermented liquors and ardent spirits." It should

be clearly understood that it is no reflexion on the quality of the Metropolitan Water Board supply to acknowledge that in some quarters this preference still exists.

In the next year (1851) the Government appointed yet another Commission, generally known as the Chemical Commission, to report upon the chemical qualities of the water supplied by the Companies. A great deal of their report, which was issued in June 1851, was concerned with the hardness of the London water, and, while expressing a preference for softened chalk spring water as the ideal, the Commission nevertheless recommended in favour of the Thames, provided that the intakes were removed above Teddington Weir and the whole of the water filtered.

The prominence given to the hardness of the water, to which the first references were made in the reports of the General Board of Health and the Chemical Commission, arose from the then recent work of Dr Clark of Aberdeen, who, in 1841, took out a patent for "a new mode of rendering certain waters less impure and less hard by the well-known method of the addition of lime." Dr Clark also invented "Clark's Scale" by which hardness is measured in grains of calcium carbonate in one Imperial gallon, or in parts per 70,000. It is now usual to express the hardness in parts per million, and on this latter method the average hardness of the water at present supplied from the Thames, Lee, and chalk wells, is approximately 230, 270, and 300 respectively. In passing, the reference in the patent to rendering the water "less impure" is interesting in view of the later development of the excess lime process.

Another interesting fact emerging from a perusal of contemporary evidence and reports is the consciousness of doctors and chemists that the appraisement of the purity of the water based on chemical analyses left much to be desired. They appear to have been groping for an explanation, which always eluded them, of the connexion between water and disease, and it was not until bacteriological methods of examination were introduced some years later that this link was finally established. So far as London is concerned, the first routine examination of the water by this method was undertaken by Dr Percy Frankland in 1885.

METROPOLIS WATER ACT, 1852

In 1851, the Government at length took action and the Home Secretary introduced a Bill for the amalgamation of the Water Companies. The Bill failed but in the following year the first Commissioner of Works presented another Bill which passed into law as the Metropolis Water Act, 1852. Its provisions had wide-reaching effects and resulted in the immediate construction of works to the value of nearly two and a quarter million pounds.

Briefly, the requirements of this Act were as follows.

After the 31st August, 1855, the Companies were prohibited from

taking water from any part of the Thames below Teddington Lock or from any tributary stream at any place below the highest point to which the tide flowed. All reservoirs within a distance of 5 miles of St Paul's were to be covered unless the water were filtered after leaving the reservoir. In addition, all water was to be filtered unless drawn from wells.

As might be expected, these requirements resulted in extensive works being undertaken by the Companies. The Lambeth Company, which had been forced by the bad condition of the water at Hungerford Bridge to anticipate this measure, completed their new works at Ditton in 1852 and closed their intake at Belvedere Road in 1853. Besides being the first of the London Waterworks to be constructed above Teddington Weir, this new station was remarkable for the pumping plant which it contained. Before deciding on the machinery, Simpson asked David Thomson, M.I.C.E., the Manager of Messrs William Simpson's Engine Works at Belgrave Road, Pimlico, and Dr William Pole, M.I.C.E. (afterwards Honorary Secretary of the Institution) to investigate the type of engine which should be employed. Thomson proposed compound rotative beam engines which, so far as can be ascertained, had not previously been used for waterworks purposes, and he was subsequently entrusted with the design and manufacture of two pairs of this type of engine, each of 300 horse-power. He introduced an innovation into these engines, namely, the bucket-and-plunger pump, by means of which water was delivered on both the up and the down stroke. This arrangement had been suggested by Smeaton in 1759, but it appears that hitherto it had not been applied. The firm of James Simpson & Co., as it subsequently became, built large numbers of these engines for use in Great Britain and elsewhere.

Of the other Companies, the Chelsea built a new works at Surbiton adjacent to the Lambeth Company's Ditton works, while the Southwark and Vauxhall, the Grand Junction, and the West Middlesex Companies, who employed the same consulting engineer (Mr Joseph Quick, M.I.C.E., also Engineer to the Southwark and Vauxhall Company), constructed intakes and engine houses at Hampton and pumped raw water to their respective works at Battersea, Brentford (Kew Bridge), and Barnes through mains specially laid for that purpose.

On the other side of London, the New River Company built filter beds at Stoke Newington and New River Head, the East London Company installed filtration and pumping plant at Lea Bridge, while the Kent Company had already built filters at Deptford.

Supplies from Underground Sources

Although from time immemorial water supplies have been obtained from wells, no serious attempt seems to have been made to obtain a public supply from the Chalk under London until 1833, when the Hampstead Water Company (later, in 1859, absorbed by the New River Company)

sank a deep well at East Heath Road near the south-west corner of the lower of the Hampstead Ponds. The yield was small and the well became disused by 1858.

The first well sunk by the New River Company was at Hampstead Road (by Warren Street Tube Station) in 1838, and this was filled-in some time before 1889. In 1846 and 1848, the Company also sank shallow wells at Cheshunt, Amwell End, and Amwell Hill respectively, from which water was pumped into the New River, and in 1853 a new Company, styling itself "The Plumstead, Woolwich and Charlton Consumers Pure Water Company," sank a well at Plumstead from which they afforded the first public supply of softened water, the method used being the excess-lime process. Nevertheless, the Company was not a success and it was purchased by the Kent Company in 1861. In spite of the fact that the latter Company had constructed filter beds at Deptford to purify its supply from the River Ravensbourne, the results were not satisfactory and in 1856 the Company sank a well about 95 feet deep into the chalk. By a coincidence, the works had been located near the Wimbledon-Deptford fault and a prolific supply was obtained. Additional wells and borings were subsequently sunk at this site and the River Ravensbourne was abandoned as a source of supply in 1863. Today the station still yields about 4 m.g.d. from the Chalk. Other well stations in Kent and the Lee Valley quickly followed and eventually five of the eight Water Companies obtained supplies from underground sources.

The Coming of Storage

Except for two small reservoirs belonging to the New River Company at Cheshunt and dating from about 1835, all the early reservoirs (apart from service reservoirs) had been designed for the settlement of the suspended matter in the water, but in the early sixties the need for storage began to be felt in the Lee Valley, where the increasing demands coupled with the low summer flows of the River Lee impelled the East London Company to construct their first reservoir to be "available in times of drought." From then onwards, more and more reservoirs were constructed in this valley until, with the recent completion of the William Girling Reservoir, all the available sites have been utilized.

In the Thames Valley, the Chelsea and Lambeth Companies constructed reservoirs at Molesey and Walton in 1871, but, curiously enough, the purpose of these was to provide water in times of flood when the river water was too turbid for use. It was not until more than 20 years later, due to the findings of Lord Balfour's Commission and to the fact that the demands were overtaking the authorized abstraction, that considera-tion was given to the construction of large reservoirs for use in times of drought, when the Southwark and Vauxhall Company promoted a Bill for two reservoirs at Walton, the Lambeth Company for one at Island

Barn (Molesey), and the Grand Junction, New River, and West Middlesex Companies jointly for two reservoirs at Staines.

The Duke of Richmond's Royal Commission

Notwithstanding the improvement in the quality of water resulting from the removal of the intakes from the lower reaches of the river, apprehensions were felt about the discharge of sewage into the upper reaches of the Thames, and in 1866 a second Royal Commission (the Duke of Richmond's) was appointed, with wide terms of reference, "to inquire into the present water supply of the Metropolis and whether there are other districts in addition to the high districts in England and Wales from which a good supply of unpolluted and wholesome water can be obtained and to report . . . which of such sources are best suited for the supply of the Metropolis and its suburbs." Amongst the members of the Commission were Mr T. E. Harrison, a railway and dock engineer, who became President of the Institution in 1874, and Sir Joseph Prestwich, the geologist. The Secretary of the Commission was that remarkable man, Dr William Pole, to whom reference has already been made.

This Commission, which was the first official body to consider proposals for a supply of water to London from a distance, took a great deal of evidence and considered a number of schemes. These included a proposal by Mr J. F. La T. Bateman (later President of the Institution) to obtain water from gathering grounds lying south of Snowdon and draining into the Severn, and that of Messrs G. W. Hemans and R. Hassard, MM.I.C.E., for a supply from the Lake District by damming the outlets of Thirlmere and Haweswater (now both utilized by Manchester) and by obtaining a small supply from Ullswater.

Another Welsh scheme was put forward by Mr Hamilton Foulton, M.I.C.E., for tapping the headwaters of the Wye, whilst a Mr Remington advocated the Derbyshire hills.

The Commission also considered a number of suggested methods of providing water for London from the Thames, the Lee, the Chalk and Oolite formations in the Thames Valley, and a few miscellaneous sources.

At the end of a report consisting of more than 120 pages, the Commission set out their findings in which they rejected the Lake District and the Welsh schemes on financial grounds and expressed the opinion "that the River Thames, supplemented if necessary by works for storing the flood waters, together with the River Lee and water obtainable from the Chalk to the south and south-east of London, as well as probably from the Lower Greensand, will furnish a supply sufficient for any probable increase of the Metropolitan population." Then followed some remarks upon the quality, in which it was stated that there was no evidence that the water then supplied by the Companies was not generally pure and wholesome,

and that whilst this water was hard, it was not injurious to health, but that the filtration process was in many cases improperly performed.

Although provisions had been included in the 1852 Act under which a constant supply could be required, they proved in practice to be of no value and for many years the lack of this essential amenity had been the cause of complaint and ill-feeling against the Water Companies. The Commission gave consideration to this question and recommended that the system of constant supply should be promptly introduced but since in their opinion this could not be effected by private companies on account of the difficulties which these companies would have in obtaining entrance to premises and exercising control over fittings, they were, in consequence, of opinion that the management of the water supply should be entrusted to a public body.

With regard to the future population and demands, the Commission considered that the former might rise to 4½ or 5 million persons and that 200 m.g.d would be the most that need be reasonably looked forward to for the Metropolitan supply.

As a result of the Commission's report, the Government passed the Metropolis Water Act, 1871, which contained provisions for the extension of the constant supply. It also required the Companies to make regulations for governing the "waste or misuse" of water and gave them power to control the use of water fittings. Apart from the appointment of an independent Water Examiner, whose duties were to ensure that the requirements of the Act of 1852 as to the filtration of domestic supply were carried out, the 1871 Act did not otherwise disturb the control or the operations of the Water Companies.

The London County Council and Lord Balfour's Royal Commission

For the next few years the Companies continued to develop their works peacefully to meet the rising demands but in 1889 a new protagonist appeared on the scene. This was the London County Council, which had come into being consequent upon the passing of the Local Government Act of 1888. The Council immediately directed their attention to the water supply, formed a special Water Committee, obtained powers to spend money on these matters, and expressed strong views that the water supply to London should be under the control of a public authority. As a result of their representations to the Government, a third Royal Commission was appointed in 1892 under the Chairmanship of Lord Balfour of Burleigh, part of whose terms of reference was :—

> "Whether, taking into consideration the growth of the Metropolis and the districts within the limits of the Metropolitan Water Companies and also the needs of localities not supplied by any Metropolitan Company but within the watersheds of the Thames and Lee, the

present resources of these Companies are adequate in quantity and quality and, if inadequate, whether such supply as may be required can be obtained within the watersheds referred to, having due regard to the claims of the districts outside the Metropolis but within those watersheds or will have to be obtained outside the watersheds of the Thames and Lee,"

This was an exceptionally strong Commission and, in addition to the Chairman it consisted of six members. Two of these, Sir George Bruce, and Mr James Mansergh, were Presidents of the Institution in 1887–88 and in 1900 respectively. The other members of the Commission were Sir James Dewar, the physicist, Sir Archibald Geikie, the geologist, Sir William Ogle, a Doctor of Medicine and statistician, and Mr G. H. Hill, M.I.C.E., a consulting water engineer.

The Commission received a great deal of important and interesting evidence on engineering, geological, and other subjects connected with the water supply to the Metropolis, including the potential supply available from the Thames and the Lee and the underground sources in the vicinity of London, but they did not consider any scheme for bringing water from distant sources such as Wales.

The report, proceedings, and appendices, published in 1893, contain a mass of valuable information upon the London water supply in all its aspects. In their findings the Commission stated that they were satisfied that the water then supplied to the consumers in London was of a high standard of purity and that, with adequate storage, the resources within the watersheds of the Thames and Lee were sufficient for a long time to come. The Commission considered that in 1931 the population to be supplied in an area of 845 square miles would be about 11¼ million persons and, adopting a figure of 35 gallons per head per day for their future requirements, they estimated that the consumption in that year would be approximately 394 m.g.d.

In dealing with the resources of the Thames and Lee watersheds in the vicinity of London, the Commission estimated these to be :—

	m.g.d.
From wells and springs in the Lee Valley and in the Kent area . . .	67½
From the River Lee with additions to the present storage system .	52½
From the River Thames by the construction of storage reservoirs at no great distance above the present intakes of the Companies . . .	300
	420

Considering the relatively few years for which the river gaugings were available and the limited extent to which the wells had been developed at the time of the Commission, these estimates, in the light of more than 50 years' subsequent experience, are remarkable for their accuracy.

Although the Government took no action upon this report, the findings did not satisfy the London County Council. That body disagreed with

the proposed storage scheme and, while reiterating their views that the water supply should be under public control, expressed the strong opinion that additional supplies should be obtained from a purer source than either the Thames or the Lee. They, therefore, instructed their Chief Engineer Mr (later Sir Alexander) Binnie, who was President of the Institution in 1905, to prepare a scheme for a supply from Wales.

Lord Llandaff's Royal Commission

In their campaign against the Water Companies, the London County Council obtained gratuitous assistance from an unexpected source. The rainfall in 1895 and in the early part of 1896 was below the average, and in consequence the flows in the River Lee were abnormally low. Since the East London Company did not possess sufficient storage, the water supply to the East End had to be drastically reduced during these summers. This, and the attempts by the London County Council in the Parliamentary Sessions of 1896 and 1897 to obtain powers to purchase the Water Companies, resulted in the appointment, in May, 1897, of the fourth and last Royal Commission under the Chairmanship of Lord Llandaff to inquire, *inter alia*, as to whether " . . . the Undertakings of the Water Companies should be acquired and managed either :

(a) by one Authority ; or
(b) by several Authorities ; and if so,

what should be such Authority or Authorities."

Only two engineers served on this Commission, namely, Sir George Bruce, who was also a member of Lord Balfour's Commission, and Major-General A. de C. Scott, R.E., who for about 12 years was the Water Examiner to the Metropolis under the 1871 Act.

Much of the evidence placed before this Commission, and no inconsiderable part of their final report, dealt with finance. Nevertheless, they considered some engineering matters of great interest, one of the most important being the London County Council's scheme for a supply from Wales. This proposal was to obtain water from the Usk, the Wye and its tributaries, as well as from the Towey, the quantities varying between 121 and 165 m.g.d. for the first instalment, up to 208 m.g.d. for the completed scheme. The estimated cost of obtaining a supply of 121 m.g.d was given by Sir Alexander Binnie as a little over £10,000,000, but this was disputed by other witnesses. The Commission, however, rejected the Welsh scheme on the score of expense and endorsed the recommendations of the two previous Royal Commissions in favour of the Thames and Lee, being satisfied that, " given effective conservancy and adequate treatment of the raw water, the wholesomeness of the supply can be maintained."

Another matter which was soon to assume—and which continues to assume—great importance was dealt with in their report, namely, the

minimum flow of the river below the intakes. Upon this, Lord Balfour's Commission did not make any recommendation, though they did consider a storage scheme based on a minimum flow of 200 m.g.d. over Teddington Weir. A great deal of evidence was presented to Lord Llandaff's Commission on this subject, and in their report they expressed the opinion that the minimum flow over Teddington Weir should be fixed at 200 m.g.d. and that this should not be reduced except under special safeguards and restrictions.

On the principal matter which had been referred to the Commission, they recommended that both on engineering and financial grounds it was desirable that the Undertakings of the Water Companies should be acquired and managed by a single public authority.

The Government accepted these findings and on the 2nd January, 1902, a Bill was introduced into the House of Commons to provide for the formation of a Metropolitan Water Board to purchase and manage the Undertakings of the eight London Water Companies. On the 18th December, the Bill passed into law as the Metropolis Water Act, 1902, and the Board met for the first time on 2nd April, 1903.

The Early Days of the Metropolitan Water Board

In June and July, 1904, the Board took over the works, duties, and obligations of the eight Water Companies and also the Undertakings of Enfield and Tottenham Urban District Councils, for which they paid a total sum of approximately £47,500,000. Thus, nearly 300 years after the formation of the New River Company, the Metropolitan Water Companies came to an end. It has been fashionable to decry their achievements, but there is no denying that many of the works which they constructed and which are still in use are examples, and very good examples, of the best engineering practice of their day. Whatever may have been their shortcomings, one Company at least appreciated the value of their Chief Engineer and it is on record that he received in addition to a salary, certain emoluments, and some relief from income tax, a commission on all the new works which he constructed. It need hardly be added that under such an excellent arrangement the works of this particular Company were always up-to-date and fully adequate to meet the demands made upon them.

After determining procedure and deciding upon their organization, the Board took stock of their position and commenced to integrate their heritage. Their obligations consisted of an increasing supply to some 6,400,000 persons who, together with the industry in the area, required about 210 m.g.d.

The future population and demands of Water London had been the subject of investigations by the last two Royal Commissions. Lord Llandaff's Commission estimated that the population to be supplied in

1941 would be about 12 million persons and, further, that an allowance of 35 gallons per head per day for all purposes would then be ample. Thus, the total demands in 1941 were expected to be about 420 m.g.d. and these figures were adopted by the Board in preparing their programme of new works.

The assets on taking over were, in the light of present-day experience, not easy to define. So far as the wells were concerned, many of the yields given in evidence proved later to be on the optimistic side, whilst the Lee had already given signs, and later conclusive evidence, of being overdrawn. In the case of the main source, the Thames, the amount which could legitimately be abstracted was becoming inadequate. The conditions of abstraction did, however, include the important and favourable provision that 130 m.g.d. could be abstracted irrespective of the flow in the river. This was usually referred to as the "unrestricted right." It was, however, evident that more storage was required and that, sooner or later, a minimum flow would be imposed.

With regard to the supply from the Lee, powers for as much storage as that valley could accommodate had been bequeathed by the East London Company and, therefore, the first major task of the Board was to secure authority for the construction of additional reservoirs in the Thames Valley.

Thames Storage, the Statutory Flow, and Powers of Abstraction

Having determined as a matter of policy to continue to take water from the Thames and basing their calculations on the flows of 1899 and on the then existing conditions of abstraction, the Board decided to apply to Parliament in the Session of 1910–11 for powers to build one reservoir near Sunbury and seven other reservoirs, having a joint capacity of about 20,000 million gallons, in the vicinity of Staines. Of these, the Sunbury Reservoir was withdrawn before the Bill was considered, two were thrown out by the Parliamentary Committee, two were subsequently withdrawn by the Board, and powers for the remaining three were granted. These latter were eventually constructed, two being merged into the Queen Mary Reservoir (6,679 million gallons) and the third, enlarged under powers of the 1935 Act, to form the King George VI Reservoir, Staines (4,466 million gallons).

In the same Session, the Thames Conservancy introduced a Bill dealing, amongst other matters, with the Board's powers of abstraction, under which the Board were to be required to give up their "unrestricted right" to take 130 m.g.d. in exchange for additional powers of abstraction. By agreement between the two Boards, it was proposed that a statutory minimum flow of 140 m.g.d. should be maintained at Teddington Weir after the Water Board had constructed further storage, the reason for

adopting this figure being that the calculated amount of storage based on a minimum flow of 140 m.g.d. would be the same as if the existing conditions of abstraction, including the "unrestricted right" to 130 m.g.d., remained in force.

Both Bills were considered together by the same Joint Select Committee of the two Houses and attracted considerable opposition. The result of the Water Board's application has already been stated whilst, in the case of the Conservancy Board's Bill, the Committee decided on a statutory flow of 170 m.g.d. As the Conservancy asked for 140 m.g.d. and their opponents pressed for 200, it is not difficult to follow the abstruse calculations which took place in the Committee Room while the contending parties waited in the corridor. Provision was also made in the Act, and confirmed in subsequent Acts, whereby the Local Government Board and their successors could, in conjunction with the Ministry of Transport, reduce the statutory flow in an emergency.

The conditions of abstraction have since been altered from time to time and the Board have now powers to abstract an average of 300 m.g.d. (400 m.g.d. after the construction of either Wraysbury or Datchet reservoirs) during any year with a maximum of 1,200 million gallons on any one day, subject always to the maintenance of the statutory flow at Teddington Weir. As a matter of interest, the unrestricted right to take 130 m.g.d. came to an end in 1926 when the Queen Mary Reservoir was brought into use.

Having dealt briefly with the historical background of the Undertaking and in particular with the supply from the Thames, which may be described as a river supply assisted, when required, by reservoirs, I would like to conclude with a few observations on the adequacy of the Board's resources, but before doing so it is desirable to place on record some particulars of the Rivers Thames and Lee, as well as of the underground sources, and to make a brief reference to the possible demands in the future.

The River Thames and the Thames-Derived Supply

The catchment area of the River Thames above Teddington Weir is 3,812 square miles and over this, the standard average rainfall is 28·21 inches. Chalk and other limestones, sandstones, and clay are the principal geological formations in the valley, and since about two-thirds of this area is permeable or semi-permeable and, in addition, there are extensive deposits of gravel, the flow is well maintained even during long periods of low rainfall.

The standard average natural flow at Teddington Weir is 1,357 m.g.d. for the year, and for the month of lowest flow (September) it is 528 m.g.d. In the summers of drought years, however, the average daily natural flow during a month is often about half this amount, the lowest recorded being 205 m.g.d. in July, 1921.

Records of the natural flow of the Thames at Teddington exist from 1883 and from these a good indication of the quantities of water likely to be available in dry years can be obtained. Owing to the lag between the incidence of rainfall and the emergence of the water from the springs, storage calculations are based on river flow records, which in drought years follow a fairly regular elongated U-shaped pattern. The drought years have been 1899, 1921, 1934, 1944, and 1949, and if calculations are made to ascertain the amount of storage required to maintain the present supply, it is found that 1921 was the most severe drought and denoting this by unity the relative severity of the series is :—

1921	1.00
1934	0·99
1944	0·91
1949	0.69
1899	0·69

In their early days the Board estimated their storage requirements on the 1899 flows. The information furnished by the later gaugings shows that considerably lower flows may be expected in drought years and it has now been decided to adopt the flows of 1944 as a standard, leaving the supply in the still more severe droughts of the 1921 and 1934 types to be taken care of by the reduction of the statutory flow. On this basis the maximum economic yield of the Thames during a drought similar to 1943–44 would be about 345 m.g.d., for which a gross reservoir capacity of some 52,500 million gallons would be needed. Any attempt to augment the supply by still further increasing the storage would result in the provision of reservoir accommodation which—during a repetition of this particular type of drought—could not be completely refilled during the winter and, in consequence, the river would then be over-reservoired.

The River Lee

Whilst there is still ample water available from the Thames to increase the supply, provided that sites for additional reservoirs can be found, the River Lee, from which the Board have the right to abstract practically the whole flow, is overdrawn. The river is gauged at Feilde's Weir, Hoddesdon, and owing to excessive pumping of undergound water in its valley, its dry weather flows are diminishing. Whilst the standard average daily natural flow for the year is 110 million gallons, monthly average flows of only 16 m.g.d. have been recorded for 2 successive months. Besides this, the winter flows are often so low that they will not provide sufficient water to refill the reservoirs. In addition, the quality of the water is deteriorating, and altogether this river is a troublesome and unsatisfactory source. To safeguard and to improve the supply to East London the Board have recently sanctioned the construction of a 75-inch-diameter main, 24 miles in length, from Hampton to Chingford, for the conveyance of raw Thames

water to the Lee Valley. Owing to the difficulty of finding a path for a main of such a size in the streets of London, it is to be laid in a tunnel driven through the London clay.[1]

At present the yield of the Lee and its reservoirs in a drought year is about 44 m.g.d. and it is probable that this will decrease.

Supply from Wells

The underground supply is obtained by pumping from fifty-three wells and boreholes sunk in the Chalk and two each in the Upper and Lower Greensands. These are capable of yielding about 65 m.g.d. and, despite the overpumping in many parts of the Board's area, it should be possible to maintain this quantity or even to increase it slightly, especially since the area is now scheduled under Section 14 of the Water Act. Nearly all the wells are in the Board's Kent Area or the Lee Valley. On account of the extension of housing development into rural areas, with the consequent pipe drainage or cesspools, constant vigilance is necessary to detect and counteract any pollution which may find its way through the fissures of the Chalk into the water drawn from the wells. Further, there is now some risk of estuarine water being drawn into the Chalk adjacent to the lower reaches of the river owing to the lowering by pumping of the underground water table.

Consumption of Water

There are few persons who do not take a lively interest in mystery and detection. To the Water Engineer the consumption of water provides both ; mystery as to how much water is used and where, and detection as to his ability to find and stop waste.

Neglecting bulk supplies, the average daily supply in 1951–52 for domestic purposes was 212 million gallons, whilst the metered or trade supply was 104 million gallons. The total consumption since the Board came into being has been increasing (see *Fig. 2*) but the remarkable fact is that, of the total increase of 73 m.g.d. since 1911 (the first year for which the records of metered supplies are available), the domestic consumption has risen by only 25 m.g.d. or 13 per cent, while the increase in the metered or trade supply has been 48 m.g.d. or 86 per cent. This is not easy to explain in view of the large number of houses built since the end of the first World War, but it has to be remembered that the figure for domestic consumption includes practically all the leakage and waste and any reduction in these lessens the apparent domestic demand. The peculiarity of these figures may not be unconnected with the substitution of Venturi meters to measure the output from the works for the method

[1] P. A. Scott, "A 75-inch-diameter Water Main in Tunnel: A New Method of Tunnelling in London Clay." Proc. Instn Civ. Engrs, Part I, vol. 1, p. 302 (May 1952).

of calculation by engine counters, while, since and during the war, the scarcity and high cost of fuel have restricted the use of hot water.

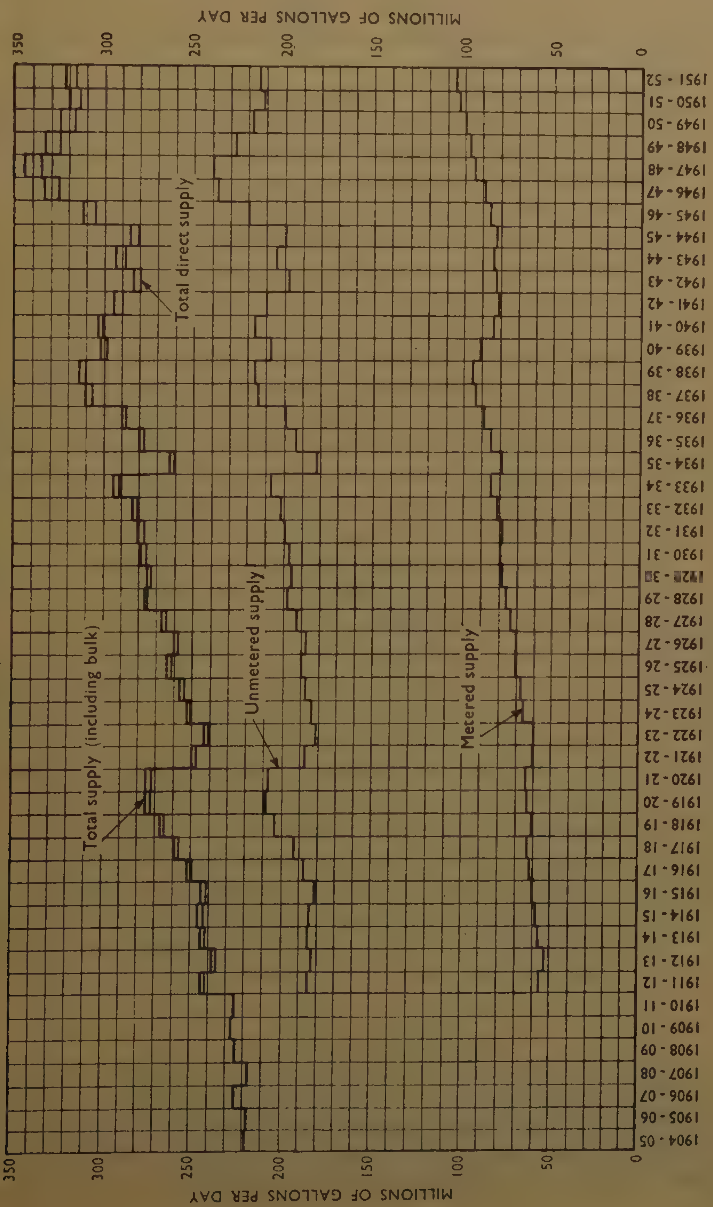


Fig. 2

AVERAGE DAILY SUPPLY 1904 TO 1952

Future Demands

And now I come to that pitfall of so many prophets, including myself—the estimation of future demands. These are influenced by the population, the quantities of water required for domestic purposes, the needs of industry, and by bulk supplies.

In 1899, Lord Llandaff's Commission estimated that the population of Water London (620 square miles) might slightly exceed 12,000,000 persons by 1941. Very fortunately this estimate has not been realized and the population in the Board's area of supply (540 square miles) at the 1951 census was 6,500,000 persons as against 6,400,000 in 1904, having fallen from the peak figure of 7,000,000 in 1931. The economic and strategic problem created by the drift of the industrial population to London was recognized by the Barlow Commission in 1940 and it is significant that the London County Council are planning for an ultimate population of 3,250,000 in that area as against an estimated population of just over 4,000,000 in 1939, though presumably a large proportion of the 750,000 will still be housed in the Board's area. What the population in this area will be eventually it is difficult to assess, but it is hoped that it will not increase appreciably above the present figure. The consumption per head per day for all purposes is now about 49 gallons, being divided into 33 gallons for domestic purposes and 16 gallons for trade supplied by meter. The two Royal Commissions considered that 35 gallons per head per day for all purposes would be ample, so that whilst they over-estimated the population they under-estimated the *per capita* demand.

Whilst it is not easy to predict either the future population or the demand per head per day, the estimation of the combination is even more hazardous and so Sir Jonathan Davidson, when he was Chief Engineer, analysed mathematically the trend of supply between 1904 and 1938 and projected it on to 1957. On the assumption that this followed a straight-line law, he found that the increase in the consumption was at the rate of 2·32 m.g.d. per annum and a recent calculation based on the period 1904 to 1952 showed but little departure from this figure. At the moment the consumption is slightly below the line of trend, but if no disturbing factors intervene and this trend still holds good, a total demand of about 370 m.g.d. might be expected in 1970 if this should be a normal year, but rising perhaps to 390 m.g.d if that summer were excessively hot and dry.

The Board's Resources

Let me now turn to the other side of the picture and assess the resources of the Board, first in relation to the present supply of 322 m.g.d. and then in the light of their capacity to meet a demand of 390 m.g.d., assuming that in both instances 110 m.g.d. can be obtained from the Lee and the wells.

With the existing Thames storage of 17,700 million gallons, an average daily Thames-derived supply of about 175 million gallons could be afforded during a drought like 1944, so that there is now a deficiency of some 37 m.g.d. to be made up by reducing the statutory flow.

The Board have powers to build three reservoirs at Walton, Wraysbury, and Datchet, which together would contribute some 13,000 million gallons of storage, but on account of the economic situation of Great Britain their construction is at present in abeyance. However, when these reservoirs are in existence, the reliable Thames-derived supply will be 240 m.g.d. This, with 110 m.g.d. from the other sources, will afford a total of 350 m.g.d., which will be the limit of the Board's resources until further storage is provided. Thus were the demand to reach 390 m.g.d. after the construction of the three reservoirs, the deficiency would be much about the same as it now is, that is, 40 m.g.d., and this again would have to be made up by the reduction of the statutory flow, the reduction, of course, being greater if the drought should happen to be of the 1921 or 1934 pattern.

Broadly speaking, the supply of each additional million gallons per day requires the provision of 200 million gallons of storage, so that on the foregoing estimates not only should the three reservoirs be in commission before 1970, but some 8,000 million gallons of additional storage would be needed to enable the Board to comply with their statutory requirements. It is fully appreciated that these estimates of consumption may not be realized but the figures quoted indicate that unless the increasing demand for water is slowed down or halted—and there does not appear to be any sign of either taking place—further reservoirs will be required. The provision of such reservoirs, involving as it does the selection of geologically and geographically suitable sites, with the minimum disturbance of development and agriculture, is the most difficult and costly problem with which the Board are faced, and failure to find a solution may entail the much greater expense of obtaining a supply from Wales.

Whatever view is held of the adequacy or otherwise of the statutory flow of 170 m.g.d. over Teddington Weir, it provides a valuable reserve when the programme of reservoir construction is in arrears—as it is now, due to the two wars and their aftermath—but in common with most reserves, it is not inexhaustible. The only safe method of increasing the supply from the Thames up to the economical limit is by the construction of more reservoirs.

Conclusion

And now I must bring this Address to a close without being able even to refer to many other subjects with which I would like to deal. Distribution, filtration, sterilization, and pumping, with their adherent problems, together with organization and administration, all provide topics of great interest in the work of supplying the Board's consumers with 1½ million

tons of water each day. However, when I commenced I stated that I had no lack of material and if one of my successors finds himself in my place and elects to read a Presidential Address on the London Water Supply, he too, I think, will be able to begin and end with the same statement.

It now only remains for me to express my thanks to all who have so kindly helped me with the preparation of this Address, whether by correspondence or by searching through records, and my particular thanks are due to the Board's staff, both in my own Department and in the Statistical Section of the Clerk's Department, for their great assistance and co-operation.

Dr W. H. Glanville, Past-President, moved

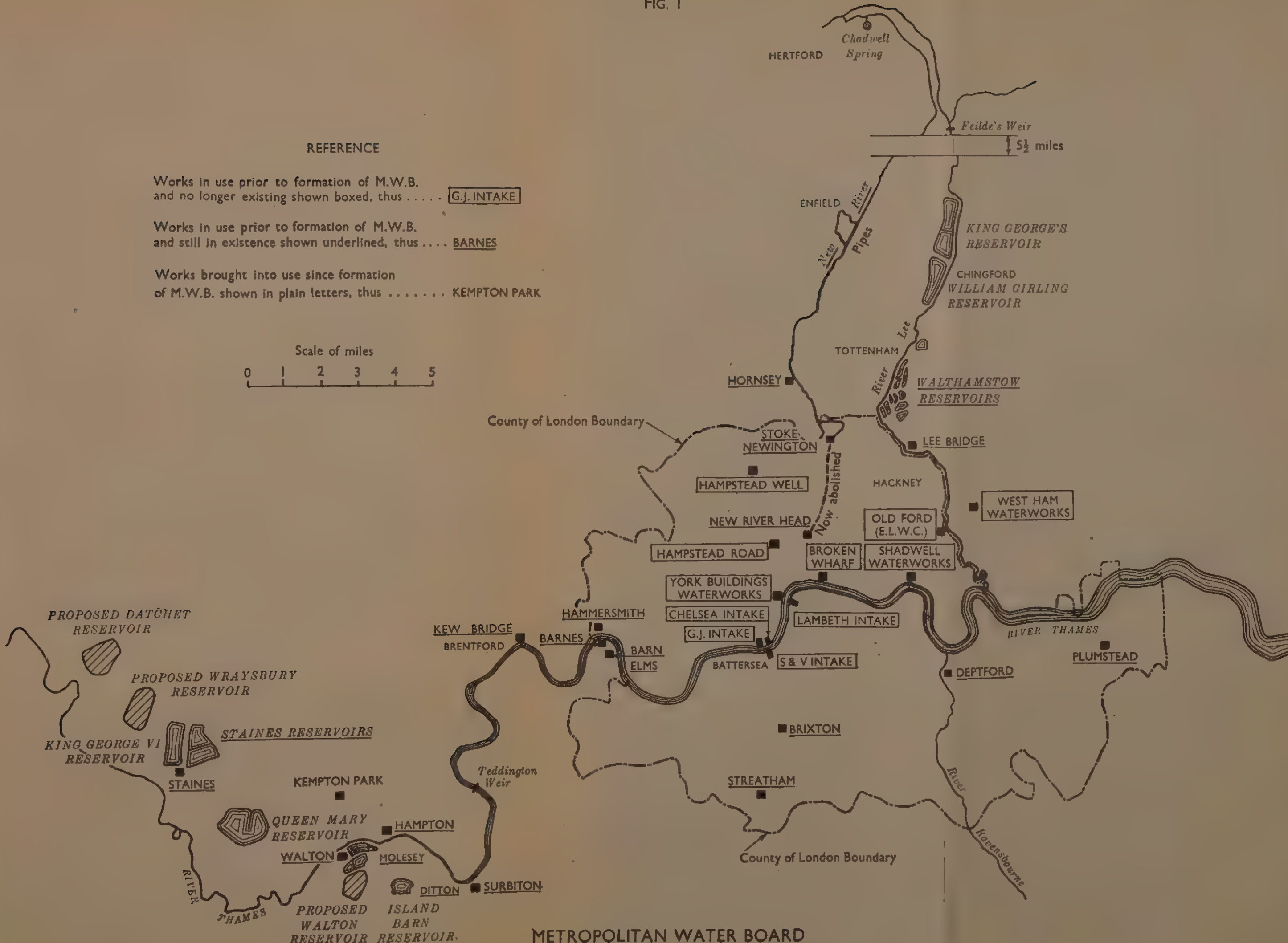
"That the best thanks of the Institution be accorded to the President for his Address and that he be asked to permit it to be printed in the Proceedings of the Institution."

Long before a President occupied the Presidential Chair, Dr Glanville observed, his troubles began. He felt that they had really begun when he found that he was confronted with the task of writing his Presidential Address, and he probably felt—at least, Dr Glanville had done so—that his anxiety grew as the days went by and the time came nearer for him to deliver that Address. All that was now over for their new President, and, whatever fears he might have had, he could now feel happy in the knowledge that he had delivered to the members that evening something which was very much to their liking and which they had thoroughly enjoyed.

Mr Cronin had told them a story of continuous progress from the time of Queen Anne onwards, a fascinating story on a subject which concerned them all very intimately, and he had told it in his usual happy way, with a touch of humour and of human understanding. He had spoken of the achievements of many great civil engineers, including the first President of the Institution, Telford. It had been very enjoyable to listen to Mr Cronin's story of the work that they had done and the efforts which they had made to improve what had been described as "a filthy fluid loaded with decayed vegetable matter." It had been interesting to learn that in 1850 it was because of the inferiority of the water that a large proportion of the population had almost been forced to use "fermented liquors and ardent spirits." Dr Glanville wondered why the engineer who had such excellent arrangements for payment with his Board did not arrange for a special supply of ardent spirits. He noticed, incidentally, that that engineer appeared to be the only one who had not been mentioned by name in the Address and, therefore, the letters M.I.C.E. did not appear!

They were all very grateful to their President for his really excellent Presidential Address, for its great interest and for the very happy way in which he had delivered it. It was clearly a foretaste of what promised to be—and they would do all they could to make it so for the President—a

FIG. I



METROPOLITAN WATER BOARD

very happy and successful Coronation Year. They wished the President every happiness in carrying out the many tasks which he would have to undertake for the Institution, tasks which he hoped he would not find too heavy in view of the tremendous load which he had to carry in connexion with his onerous duties with the Metropolitan Water Board. It was therefore with the greatest pleasure that Dr Glanville called on Mr Hartley to second the motion.

Mr A. C. Hartley, Member of Council, said that it was with particular pleasure that he seconded the vote of thanks proposed by Dr Glanville. Mr Hartley's interest in the subject of water supply started, he thought, when he had been asked in his final year in college to prepare a report comparing the water supplies of London, Birmingham, Manchester, and Glasgow. He had been wondering, since the President had been at the same college, whether that same task had been given to him, and whether that had been to some extent the reason for his so happy choice of career.

Mr Hartley noticed that the President raised his glass once or twice during the Address, but did not know whether that was advertising that the liquid was no longer a " filthy fluid " or whether the glass contained some of that " fermented liquor or ardent spirit " referred to in the Address.

Mr Hartley had had very great help before the war from Mr Cronin and his colleagues in connexion with water supplies in Abadan, where on one or two occasions he had stated that the quantity of water being handled there—largely for industrial purposes, of course—was as much as Mr Cronin was dealing with in the Metropolitan area each day. Mr Hartley and his colleagues had received great help from Mr Cronin in their work in Persia. During the war he had very kindly permitted the use of the unfinished reservoir at Staines for certain experiments and had thus greatly contributed to their success. For those reasons Mr Hartley had the greatest pleasure in seconding the vote of thanks.

The motion was carried with acclamation.

The President, in acknowledging the vote of thanks and giving permission for the Address to be printed in the Proceedings, expressed his sincere thanks to both Dr Glanville and Mr Hartley, and assured Mr Hartley that the water in the glass beside him was not Metropolitan Water Board water. He did not know whether or not, as President, he should stigmatize the Institution as an anti-social body, because it owned a private well, and thus avoided paying any contribution to the Metropolitan Water Board.

He had spoken long enough and comparisons were odious, but he could not resist the temptation to observe that Dr Glanville, in his Presidential Address two years previously, had stated that one in five of those present at that time, would, in our lifetime, be injured in a road accident. The President could give the assurance that not one in five million of the

people of London would ever get typhoid from drinking the water supplied by the Metropolitan Water Board. The audience, therefore, could go away feeling that they could drink as much water as they liked and would be perfectly safe!

He thanked them very much for the kind way in which they had received his Address. He only hoped that they had enjoyed listening to it as much as he had enjoyed writing it.

MEDALS AND PREMIUMS, SESSION ~~1950–51~~ 1951–52

For Papers presented for discussion at Ordinary Meetings :—

(1) A Telford Gold Medal to Dr Carlo Semenza for his Paper on "The Most Recent Dams by the 'Società Adriatica di Elettricità (S.A.D.E.)' in the Eastern Alps."
(2) The Coopers Hill War Memorial Prize to E. J. Hamlin, D.Sc., M.I.C.E., for his Paper on "Sewerage and Sewage Disposal in Sub-tropical Countries, with Special Reference to South Africa and Mauritius."
(3) A Telford Premium to A. A. Fulton, B.Sc., M.I.C.E., for his Paper on "Civil Engineering Aspects of Hydro-Electric Development in Scotland."

For Papers presented at Meetings of the Engineering Divisions :—

STRUCTURAL AND BUILDING ENGINEERING DIVISION

(1) A Manby Premium to B. G. Neal, M.A., Ph.D., and P. S. Symonds, Ph.D., jointly, for their Paper on "The Rapid Calculation of the Plastic Collapse Load for a Framed Structure."

MARITIME AND WATERWAYS ENGINEERING DIVISION

(2) A Telford Premium to M. C. White, B.Sc., A.M.I.C.E., for his Paper on "The Design and Construction of the New Deep-Water Quays at Leith."

WORKS CONSTRUCTION DIVISION

(3) A Crampton Prize to W. Storey Wilson, M.C., B.Sc., M.I.C.E., and F. W. Sully, M.I.C.E., jointly, for their Paper on "The Construction of the Caisson Forming the Foundation to the Circulating-Water Pump-House for the Uskmouth Generating Station."

PUBLIC HEALTH ENGINEERING DIVISION

(4) A Telford Premium to R. H. MacDonald, M.A., A.M.I.C.E., for his Paper on "Relation between Daily Rainfall and Flow of the River Shin."
(5) A Telford Premium to J. T. Calvert, M.A., M.I.C.E., and P. M. Amcotts, A.M.I.C.E., jointly, for their Paper on "Some Problems in the Disposal of Industrial Effluents and Domestic Wastes."

STUDENTS' PAPERS

For Papers read before Local Associations and the Association of London Students :—

(1) The James Forrest Medal and a Miller Prize to F. G. Johnson, M.Eng., Stud.I.C.E., for his Paper on "The River Dee as a Source of Water Supply for the Wirral Peninsula" (North-Western Association).
(2) A Miller Prize to A. D. Anderson, Stud.I.C.E., for his Paper on "The Construction of a Sewer passing through an Extensive Pocket of Running Sand" (Edinburgh and East of Scotland Association).
(3) A Miller Prize to H. A. Hope, Stud.I.C.E., for his Paper on "Notes on the Construction of Highways in Sweden" (Edinburgh and East of Scotland Association).
(4) A Miller Prize to E. T. Haws, M.A., Stud.I.C.E., for his Paper on "Survey Work for Part of the Errochty Hydro-Electric Project" (Edinburgh and East of Scotland Association).
(5) A Miller Prize to George Diggle, B.Sc., Stud.I.C.E., for his Paper on "The Respective Merits of Cast Iron and Steel Pipes in Waterworks Practice" (Northern Counties Association).
(6) A Miller Prize to W. H. J. Dobson, Stud.I.C.E., for his Paper on "The Ashford Common Works of the Metropolitan Water Board" (Association of London Students).

(7) A Miller Prize to D. F. Watson, Stud.I.C.E., for his Paper on " Soil Stabilization " (Glasgow and West of Scotland Association).
(8) A Miller Prize to Arthur Marsland, M.Sc., Stud.I.C.E., for his Paper on " The Use of Scale Models in Civil Engineering " (Association of London Students).
(9) A Miller Prize to E. W. Parkinson, B.Sc. (Eng.), Stud.I.C.E., for his Paper on " The Proposed Fairfax Street Bridge, Bristol " (South-Western Association).
(10) A Miller Prize to A. C. Allen, B.Sc. (Eng.), Stud.I.C.E., for his Paper on " Power from Water—Some Notes on Hydro-Electric Development " (Association of London Students).
(11) A Miller Prize to J. R. Kemp, Stud.I.C.E., for his Paper on " Some Considerations affecting Dock Design and Layout " (North-Western Association).

The Institution Medal and Premium (Two)

(1) Awarded on the result of an annual competition between undergraduates of the University of London.

To Ralph Berry Sims, Stud.I.C.E., of King's College, who read a Paper on " Subway Construction in New York and Toronto and Some Aspects of the American Civil Engineering Industry."

(2) Awarded on the result of an annual competition between Students of Local Associations.

To Frank Geoffrey Johnson, M.Eng., Stud.I.C.E. (North-Western Association), who read a Paper on " The River Dee as a Source of Water Supply for the Wirral Peninsula."

ELECTION OF ASSOCIATE MEMBERS

The Council at their meetings on the dates given below, in accordance with By-law 14, declared that the undermentioned had been duly elected as Associate Members.

23rd September, 1952

Home

James Ronald Adams, Stud. I.C.E.
Peter Gordon Rigby Barlow, M.A. (*Cantab.*).
Norman Frederick Batt, B.Sc. (Eng.) (*Lond.*).
George Frederick Beaven.
Roger Louis Bonafont, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Bernard William Burton, B.Sc. Tech. (*Manchester*), Stud. I.C.E.
Joseph Reginald Capo-Bianco.
Terence John Carroll, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Harold Victor Chivers, B.Sc. (*Birmingham*).
Christopher d'Altera Dakin, B.A. (*Cantab.*).
Leslie Hilton Davis, Stud. I.C.E.
Geoffrey Coxon de Rome, B.Sc. (Eng.) (*Lond.*).
Steven Robert Law Elliott, B.Sc. (*Leeds.*).
Ryan Ellis. B.Sc. (*Belfast*).
Michael Francis Ennis, B.E. (*National*), Stud. I.C.E.
Arthur Whalley Ewart.
Henry Holdroyd Ferguson, B.Sc. (*Leeds*).
Alexander Blair Garven, (Jnr.), B.Sc. (*Glas.*), Stud. I.C.E.
Frederick Grover, B.Sc. (Eng.) (*Lond.*).
William Hamilton, B.Sc. (*Glas.*), Stud. I.C.E.
Anthony Bell Harman, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Oliver Hensley, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Donald James Gemson Howard, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
James Patrick Hoyland, B.Eng. (*Sheffield*), Stud. I.C.E.
William Bennett Jarvie.
Samuel Thomas Jones.

Alistair Kinnaird, Stud. I.C.E.
Edward Albert Lee, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Brian Thomas Pughe Lewis, B.Sc. (*Wales*), Stud. I.C.E.
Norman William Herbert Lloyd.
Charles Andrew Ferguson Lucas, Stud. I.C.E.
David Trevor Mabon, B.Sc. (*Birmingham*).
Leonard Dawson Ogden, B.A. (*Cantab.*), Stud. I.C.E.
Derek Robert Leney Raybould, Stud. I.C.E.
William Royle, B.Sc. (*Manchester*).
David Edward Sharpley.
Richard Shearcroft, B.Sc. (*Edin.*).
Raymond Dudley Sheffield.
Derek John Skinner, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Norman John Smith, B.A. (*Oxon.*), Stud. I.C.E.
Francis James Sneddon, B.Sc. (*Glas.*), Stud. I.C.E.
Geoffrey Walton Taylor, M.A. (*Cantab.*), Stud. I.C.E.
Nicholas Traynor, B.Sc. Tech. (*Manchester*), Stud. I.C.E.
Richard Williams, B.Sc. (Eng.)(*Lond.*), Stud. I.C.E.
Christopher Joseph Wilshere, B.A., B.A.I. (*Dublin*), Stud. I.C.E.

Abroad

David Malcolm Bain, Stud. I.C.E.
Donald William Briant, Stud. I.C.E.
Frederick George Davies.
Robert Frank Davies, B.Sc. (*Witwatersrand*)
John Gilstain Hood, B.Sc. (*Cape Town*).
Carleton Mackey Lipscombe.
James McTaggart.
William Gibson Mahaffy, B.Sc. (*Edin.*).
Colin McDonald Matheson.
Thomas Derrick Miller, B.Sc. (*Durham*).
Ronald Foster Pegg, M.A. (*Cantab.*).
Arthur Lawrence Henry Poulton, B.Eng. (*Liverpool*), Stud. I.C.E.
Kenneth Alister Struan Robertson.
Gordon Robin Stanbrook, Stud. I.C.E.
Ian Thomas Stone.
Gordon Wallwork, B.Sc. (Eng.) (*Lond.*).

21st October, 1952

Home

Charles Kwamina Annan, B.Sc. (Eng.) (*Lond.*).
Dennis Arthur James Ballinger, B.Eng. (*Liverpool*).
James Peter Maclean Bell, B.Sc. (*Glas.*).
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William Edwin Chapman (*Stud. I.C.E.*).
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James William Jackson, B.A. (*Oxon.*), Stud. I.C.E.
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Jack Kay, M.A. (*Cantab.*).
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Alan Lightbown, B.Sc. (*Manchester*), Stud. I.C.E.
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JOHN RONALD WILLIAMS, B.Sc. (*Wales*).
KENNETH MURRELL WRIGHT, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.

DEATHS

It is with deep regret that intimation of the following deaths has been received.

Members

PERCY WALTER BERTLIN (E. 1897, T. 1926).
HARRY CUNNINGHAM (E. 1903, T. 1920).
GAVIN HEYNES JACK (E. 1916).
Professor FREDERICK CHARLES LEA, O.B.E., D.Sc. (E. 1901, T. 1918).
ARNOLD MORRIS, O.B.E. (E. 1915, T. 1935).
ERNEST PREBBLE (E. 1893, T. 1913).
JAMES SCARLETT ASCROFT WALKER (E. 1913, T. 1947).

Associate Members

WILFRED JOHN BENSON, B.Sc. (E. 1936).
CHARLES ALEXANDER CHAMBERLIN (E. 1912).
DAVID CAMERON ROBERTSON (E. 1907).
ARTHUR EDWARD WILLIAMS (E. 1892).

Student

JOHN NORMAN CROW (A. 1951).

Paper No. 5843

"The Driving and Testing of Piles"

by

Horace Denton Morgan, M.Sc. (Eng.), and Charles Kenneth Haswell, B.Sc. (Eng.), MM.I.C.E.

(*Ordered by the Council to be published with written discussion*) †

SYNOPSIS

The Paper describes the methods of driving and loading of test piles to determine their safe working loads. A number of tests are described in detail relating to several sites in Great Britain. Heavy structures such as steam generating stations and a factory were involved. Such structures are frequently situated near rivers and on alluvial ground and call for piled supports, especially since at the present time very heavy loads have to be carried while the allowable settlement is small. Pertinent questions are discussed, such as the value of pile-driving formulae and the use of jetting.

A description is given of a series of tests carried out at Abadan in Iran during a period of about 5 years. These tests included single and group-loading pile tests and uplift tests carried out in connexion with a catalytic cracking plant. In this case the whole piled area settled during construction without the application of any load, and certain of the major piled structures were subjected to pre-loading to accelerate this settlement to the point of stability. The object of this was to commission the plant at the earliest possible moment.

The Paper is accompanied by photographs, tabulated results, and graphs to illustrate the methods employed in making and interpreting the tests.

Introduction

The object of this Paper is to discuss the driving and testing of piles in order to discover their positive or bearing load at a given site. At the same time it is proposed to record some results which have been obtained, and also to describe the methods used to overcome difficulties encountered in driving piles at certain sites, especially in cases where some particular problem arose.

The situation of the kind of structure which requires a heavy foundation is usually dictated by considerations of geography. They are frequently placed near some river in alluvial ground. For this reason the use of piled foundations is common, the piles being used purely in friction or at other times to transfer the load down to some harder stratum underlying a weak upper layer.

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† Correspondence on this Paper should be received at the Institution by the 1st May, 1953, and will be published in Part I of the Proceedings. Contributions should be limited to about 1,200 words.—Sec. I.C.E.

The magnitude of concentrated loads which have to be dealt with appears to have increased during the last 20 years. In the case of steam generating stations, to give one example, stanchion loads of 1,000 tons and more have become commonplace. One of the major reasons for this is the great increase in size of the boilers. For these and other reasons the Authors believe that a fairly exact knowledge of the bearing capacity of a pile is more critical than it used to be. The difficulty is to know how to arrive at it.

A great many formulae exist which are claimed to predict the bearing capacity of a pile. They are almost all empirical or nearly so, and few have any basis of rational analysis. Possibly the more reliable formulae are the type that are based upon energy considerations and use data gained during driving. Even when successful these formulae can only indicate the driving resistance which is often a very different thing from the ultimate bearing capacity of the pile. They depend upon the equation of the kinetic energy of the hammer to the work done in giving the pile a set which can be measured. Unfortunately a number of factors which can be known only approximately intervene in this equation. In the first place the kinetic energy of the hammer is not transmitted entirely to the pile, and the proportion of energy transmitted depends upon a number of practical considerations such as the nature of the helmet and the type and condition of the material with which it is packed. It is obvious that a new grummet placed in a helmet will transmit less energy when it is new than after it has been hammered flat. Even if the exact amount of energy transmitted to a pile were known, there would remain the question of how much of it would be usefully employed in driving the pile. A proportion—sometimes a major proportion of this energy—is certainly used in temporarily compressing the pile and the ground, as well as in overcoming the inertia of the pile, which may be considerable. It is in connexion with the latter factor that the relative weight of the hammer and the pile is of importance. Methods exist for determining the temporary compression of the pile and the ground, but even when these are known in relation to the set it is not possible to determine exactly the distribution of energy between the two effects. For these and other reasons the Authors consider that most piling formulae are unreliable and believe that most engineers would share this view. The number of formulae is continually being augmented, but the Authors believe that it may fairly be said that none has yet been demonstrated to be exact in its results. Indeed, it is probable that none ever will be.

The problem has been approached in a different way by attempting to use the results of soil mechanics analysis. Soil mechanics methods may be applied in two ways. In the first case, when piles are driven through soft ground into a hard stratum below, the resistance of the pile is developed in end bearing, and the measurement of the strength of the hard stratum by means of undisturbed samples may be used to estimate the bearing

pressure which it can support, and to indicate the amount of penetration into the hard stratum which will be required. For instances such as these, soil mechanics methods are of value. The second case arises when the pile is supported purely by friction and the measurement of the internal shear strength of the ground can in principle be used to arrive at an estimate of the bearing capacity of the pile. In doing this it is usual to assume that the friction between the pile and the ground is equal to the internal shear strength of the ground, but there is no particular reason why it should be so. In one case known to the Authors, which will be referred to later, the shear resistance between the pile and the ground appeared to be greater than the internal strength of the ground. This was indicated by the fact that a withdrawn pile was seen to be covered with a layer of soil.

In practice it is a common experience that the measured shear strength of the ground varies from level to level throughout the depths of the bore, sometimes fluctuating between remarkably wide limits. In such circumstances it is logical to suppose that the total shear force between the pile and the ground cannot be arrived at except by a somewhat tedious process of arithmetical summation. It is doubtful whether such a process is of great practical value, and the Authors believe that the most effective way of performing the integration is to do so mechanically by driving a pile and then testing it.

The timing of the test piling is most important. The Author's view is that it is very desirable to carry out this work during the preliminary stages of any scheme, before letting a contract for the main works.

There are three main advantages to be gained from this procedure. First of all, any difficulties in driving are brought to light at an early stage; if jetting is to be employed various experiments can be made on the type of jet to be used and so on. Secondly, if the information obtained is made available to contractors tendering for the major work, they are able to estimate the actual cost of pile driving with greater confidence. Thirdly, much time is saved in making a start on the permanent works.

Unfortunately, in some cases it is not easy for money to be made available for this preliminary test piling work prior to the letting of the main contract.

The first step to be taken at a site is to carry out a soil survey by means of boreholes in order to ascertain the general nature and type of strata. The information so obtained will usually indicate whether the foundation is likely to require piling or not. It will also allow a preliminary estimate to be made of the length and type of pile which will be required, and whether these piles will be used purely in friction or simply to transmit the load down to some harder stratum. The driving and loading of test piles will then allow a closer assessment to be made, depending upon the amount of settlement which can be tolerated. It will be remembered in this connexion that a general overall settlement is not of so much consequence as a differential settlement between one point and another. The test piles

not only prove the suitability of a pile of a certain type, but also reveal any difficulties in driving which are likely to arise, and enable a plan of campaign to be formulated for the major works, which may involve the driving of many thousands of piles. The data obtained during the driving of the test piles is of great value later on when it can be used as a check in the driving of the permanent piles, and any general variation in the ground can readily be detected. During the progress of the main works it is usually desirable to test piles occasionally as a further check.

Methods of Driving Piles

In general, the process of driving test piles is similar to that of driving in quantity, except that greater care should be observed and the opportunity taken to make a continuous record of the various characteristics displayed by the pile during driving. It may be added that it is advisable to start driving at the beginning of the day to ensure that a test pile is completely driven in one operation.

For test piles it is the practice of the Authors to specify the use either of a drop-hammer or a single-acting steam-hammer. Steam hammers of the double-acting type are less useful for this purpose, and in any event are unsuitable for driving large piles. When using a drop-hammer actuated by a winch it is necessary for the hammer when falling to overhaul the winch drum and, consequently, some of the potential energy of the hammer is lost, the amount lost being rather uncertain. It is quite easy for the winch driver to hold the hammer on the bond and considerably diminish the effectiveness of the blow. For this reason the Authors provide for the use of a trigger release mechanism such as is illustrated in *Fig. 1*,* and specify that, at intervals during the driving of the test pile, a certain number of blows must be struck with the use of a trigger release and a free-falling hammer. It is usual to mark off the pile in feet and to record the number of blows required for each foot of penetration using a constant drop of the hammer overhauling the winch, and to revert to a free-falling hammer at regular intervals. By the use of this method the pile can be driven fairly rapidly, but at the same time an exact check is made at intervals during the driving. A free-falling hammer is invariably used while the pile is taking its final set. The results of the driving may be recorded in the manner shown in Appendix II, Table 2.

A most commonly used method of observing the set of the pile is to arrange a smooth and heavy bar close to the pile, but not in contact with it, the bar being supported in such a way as to be independent of the movement of the pile or the ground. In the early stages of driving it is sufficient to use the bar as a ruler, and to mark the pile with a piece of chalk. If greater accuracy is required a sheet of paper may be fixed to the side of the pile and a pencil may be used. This method is also convenient for

* *Figs 1* to *6*, *8* to *11*, *19* to *21*, *23*, and *24* are half-tones and will be found between pp. 64 and 65.

recording the temporary compression of the pile and the ground. In order to do this a line is drawn from side to side across the paper during the period of impact of the hammer, as is shown in *Fig. 2*, and the resulting diagram indicates not only the temporary compression but also the permanent set.

Occasionally, it may happen that whilst there are sound technical reasons for wishing to obtain a certain penetration, difficulties may occur in driving which make the progress too slow and result in risk of damage to the pile. In such circumstances the use of water jetting may be resorted to, the jet or jets being applied to the toe of the pile and water fed through a pipe or pipes attached to it at intervals throughout its length or, alternatively, through a pipe cast in the pile. When the former method is used on the main contract the pipe may be arranged so that it can be unscrewed and withdrawn from above, only the jet or jets being lost.

There are two ways of using water jets. In the early stages of driving, and indeed sometimes throughout this process, the pile may be lifted and lowered with the water jets running and the pile surged down almost to its final position. It is sometimes convenient, however, to use the hammer while jetting. The last few feet of penetration are invariably obtained without the use of water jets and with the hammer alone.

The Authors would like to emphasize strongly the importance of using a monkey of sufficient weight. Analytical methods and practice both indicate that it is essential that the hammer should have a weight which is significant compared with that of the pile, otherwise the greater part of the blow is lost in the temporary compression of the pile and the ground. A slow heavy blow from a large hammer is very much more effective than a large number of blows of little weight from a small hammer. The small hammer simply spalls the pile and tends to damage the head much more rapidly. Unfortunately, there is considerable prejudice to be overcome in this respect and contractors frequently show reluctance to use a heavy hammer—a reluctance which is often traceable to the fact that the winches and pile frames are not equal to their task. The Authors do not wish to imply that suitable heavy pile-driving equipment is not available in Great Britain, but it does sometimes happen that a contractor does not possess it, or at any rate does not have a sufficient number of frames of the type required. The Authors can remember a number of occasions when the suggested use of a heavier hammer has been adopted with successful results.

It is often economic to drive isolated piles by means of false leaders, thereby dispensing with the use of the normal type of pile-driving frame. Illustrations of this method are shown on *Figs 3* and *4*. It should be emphasized that false leaders should not be employed for test piles, and even for permanent piles the work should be very carefully supervised.

Methods of Applying Test Loads

In general there are three main ways in which the test load may be applied to the pile. The relative merits of these methods are discussed

below, but it frequently happens that the economics of the test decide which method is to be used. The amount of money allocated for test piling, the space available, and the supply of suitable materials all have to be considered, and in cases of isolated sites, the question of the availability of plant and materials may constitute a problem.

The methods of applying the loads to single test-piles may be classified as follows :—

(1) By means of a jack using other piles as anchors or some alternative method of dealing with the upward thrust.
(2) By applying the load directly on top of the pile.
(3) By jacking against a platform carrying kentledge greater than the total load.

If suitable piles or other means of taking the thrust are available, the use of a jack is usually the most economical way in which a loading test can be undertaken, but constant attention must be given to the jack throughout the test. An illustration of such a test is shown in *Fig. 5*. Using this method a typical pile may readily be selected for a check test, wherever it is felt desirable on a piled site, as the constructional work proceeds.

Given the facilities, the second method is the best, and in this case it is advantageous for the loading platform to be designed so as not to transmit a bending moment to the head of the pile. For a simple loading platform, such as is shown in *Fig. 6* it is obvious that at all times the load must be added in such a way as to maintain the centre of gravity of the whole load close to the axis of the pile. Sometimes, according to the nature of the kentledge, the centre of gravity of the desired load may become somewhat high, and it is necessary to take steps to limit the movement of the load in all directions. One method of doing this is to provide corner supports between the platform and the ground, folding wedges being used so as to give the platform the degree of freedom desired. This practice can be inconvenient at times when it is desired to leave a pile unattended during the night. The use of a simple platform is most inconvenient when a pile is approaching its ultimate bearing capacity. At this point there may be a sudden increase in settlement, which may be accompanied by a sideways movement of the head, and if the test load has a high centre of gravity it may be that it will take charge and break the head of the pile, or alternatively, if the movement is checked by ground supports, the pile is relieved of load and useful information may be lost. The method of applying a load direct to a pile which the Authors prefer is to use a platform having an extension in two directions at right angles. This enables the centre of gravity of the load to be kept within the quadrant formed by the two extensions. Hydraulic jacks with pressure gauges are placed under the free ends of the two arms and allow the reactions at these two points to be read at any time. The total reaction on the pile is then the weight

of the kentledge minus the two reactions on the jacks, which should be approximately equal. This method has much to recommend it; the load is at all times under control and the reaction on the pile is known within quite sufficient limits of accuracy. Figs 7, Plate 1, and *Fig. 8* show details of such a platform and its use on site. A variation to this method is to insert a jack between the platform and the pile head, merely as an instrument to record the test load, which is applied gradually. In this case, no jacks are needed under the outriggers. *Figs 9* and *10* (between pp. 64 and 65) show such a test in progress.

Lastly, jacking against the full load is a method often used, but it suffers from two main disadvantages. It does not make full use of the kentledge available when more than one test pile is to be loaded, and it requires constant attention on the jack.

For all these tests the load should be applied in equal increments.

Methods of Measuring the Settlement

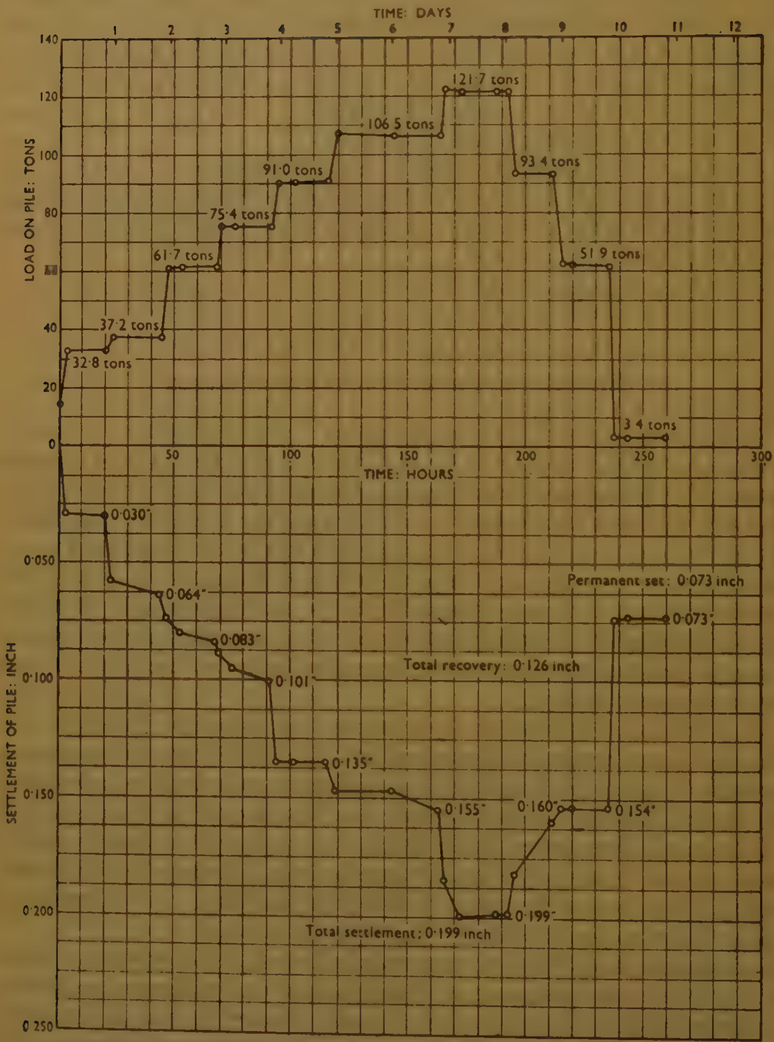
It has been realized for some time that the use of a Dumpy level to measure settlement of piles does not in general give results to the desired accuracy. Under ideal conditions, however, it is possible to use a Dumpy level and to obtain satisfactory results by applying a suitable scale to the side of the pile, but in order to obtain these results the instrument ought not to be moved throughout the period of the test, and this is often inconvenient. It is also obviously possible for the instrument to be disturbed slightly without the knowledge of the operator, unless constant vigilance is maintained, and this is not always practicable in the case of a test that may last for several days.

It is now usual to measure the settlement by more direct means. One method is to use a horizontal bar fixed to stakes driven into the ground, as shown in *Fig. 11.* With reasonable care an accurate spirit-level astride the bar can give readings on graph paper fixed to the pile to an accuracy of $\pm$ 0·02 inch. The stakes should be clear of any possible disturbance by the pile in its downward movement under load. It may be added that reading direct from a bar situated under the kentledge can be hazardous in cases where no proper stabilized platform is available.

Another method of direct observation often employed nowadays is the use of a micrometer dial gauge. These gauges can be obtained to almost any desired degree of accuracy, and can be read with ease, if necessary by means of a telescope outside the area of the test frame. The use of a dial gauge is perhaps the most common method employed nowadays as well as the most satisfactory.

On some of the tests at Abadan a modified clockwork recording barograph was used to measure the settlement, with the advantage that it gave a continuous record of any movement of the pile.

Fig. 12 (a)

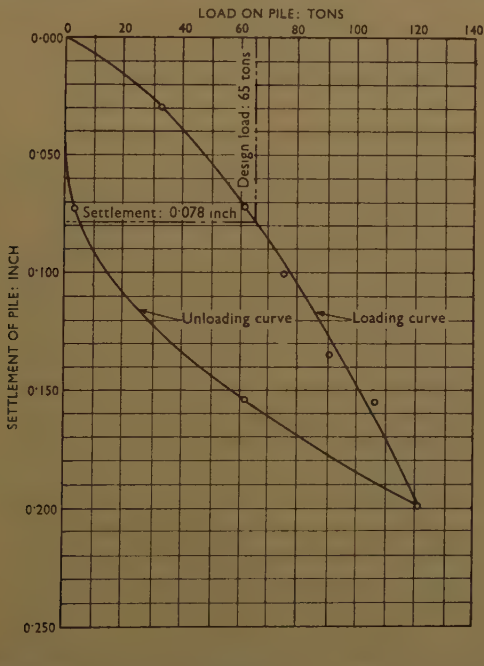


LOAD/TIME AND SETTLEMENT/TIME DIAGRAMS FOR TESTS ON PILE NO. 3, KEADBY POWER STATION

Fig. 12 (b)

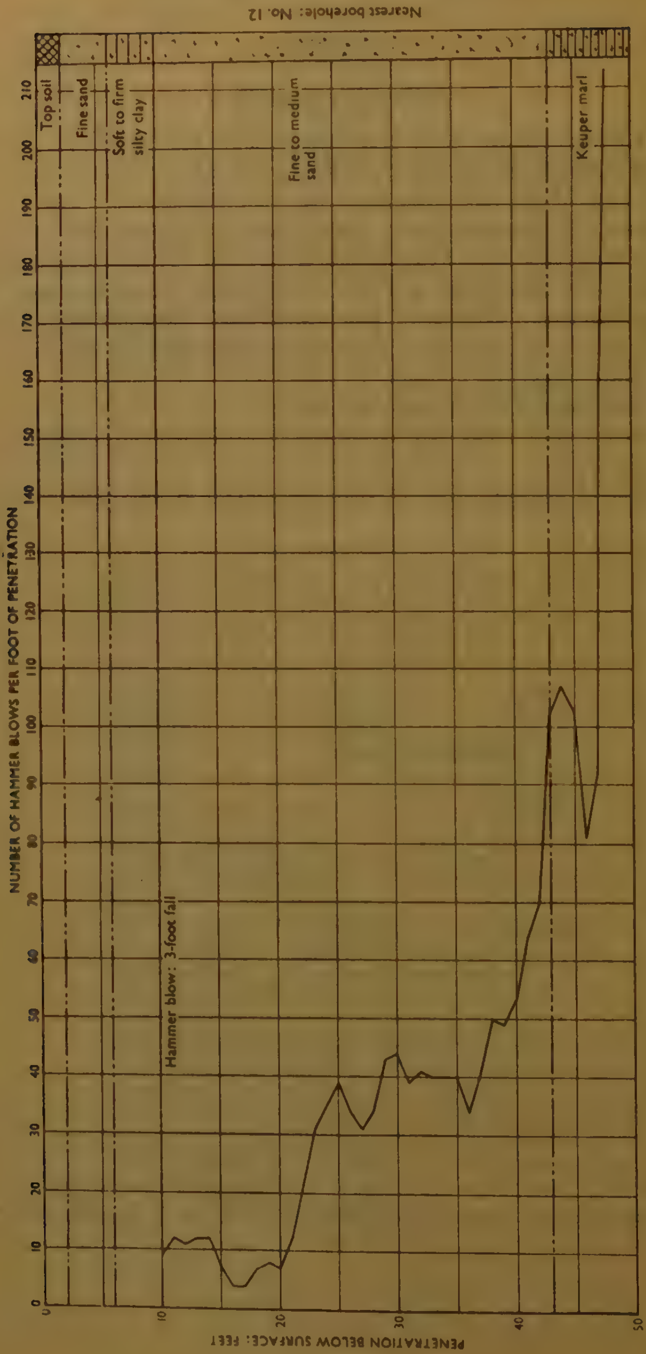
Details of Test Pile

Size : 14 inches square, reinforced concrete, 50 feet long.
Reference number of pile from pile plane : T.P.3
Serial number of pile : 3. Nearest borehole : No. 12.
Date driven : 20 February 1948. Date loaded : 1 March 1948.
Driving characteristics.—Final penetration : 48 feet below ground level. Final set : 213 blows per foot, using 4-ton steam-hammer with a fall of 3 feet. Weight of pile : 4·55 tons. Weight of helmet and dolly : 0·42 ton. Type of packing : timber and sawdust.
Condition after driving : plumb.
Type of kentledge : 10-cwt cast-iron blocks.
Note :—Settlement measured by means of a dial gauge, reading to 0·001 inch.
Weight of loading frame (3·4 tons) included in test loads shown.



Load/Settlement Diagram for Tests on Pile No. 3, Keadby Power Station

Fig. 12 (c)



Record of Pile Driving (Pile No. 3), Keadby Power Station

For details of test pile see *Fig. 12 (b)*, p. 51.

Single Pile Tests

A representative selection of examples has been included to illustrate the driving and test loading of some single piles on several different sites. In *Figs 12* and *13*, and in Figs 16, 17, and 18, Plate 2, the results are shown in a form which, it is suggested, gives the relevant information in a convenient manner. It should be noted that an effort has been made to achieve the ideal of a uniform rate of increase or decrease of load.

Keadby Power Station

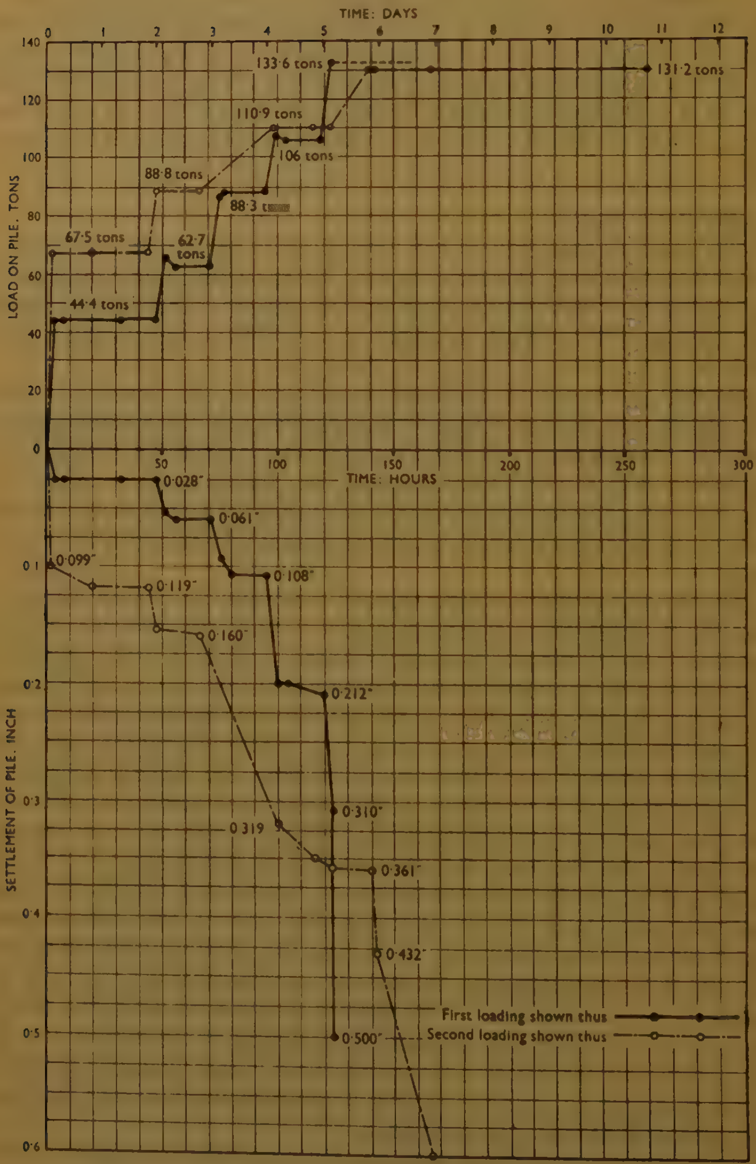
The steam generating station at Keadby on the River Trent is about 9 miles above the river mouth, in the County of Lincolnshire. The site is on a flat alluvial plain and the strata consist of silts, sands, and some peat to a depth of about 40 feet. These overlie the Keuper marl.

On this site four 16-inch-square precast reinforced-concrete test piles were driven and loaded. *Figs 12* and *13* illustrate the results obtained from two of these piles. Three of the four piles were 50 feet in length and the fourth was only 35 feet in length, the object being to check the behaviour of a shorter pile which did not penetrate to the marl. As will be seen, the shorter pile failed and all subsequent piles were driven into the marl.

The driving of the test piles was not easy, and later when driving in quantity the work became extremely difficult and piles were driven at far too slow a rate to achieve reasonable progress and cost. The contractor experimented with various forms of jetting both with air and with water. The method finally adopted was to jet with water throughout until the marl was reached and to avoid percussion driving. At two points the piles were stopped by strata of clay. They were then lifted and lowered a few times through a distance of 3 to 4 feet until the clay band had been penetrated. The piles continued still without the hammer until the marl was encountered. The piles were then driven into the marl some 4 or 5 feet in the normal manner by using the hammer. The average time for the whole operation was about 20 minutes per pile and in this manner more than 7,000 piles were dealt with. The quantity of water delivered to each pile varied between 100 and 200 gallons per minute at a pressure of 300 to 400 lb. per square inch. The water was conveyed down the pile by means of a 2-inch-internal-diameter tube clipped to the side of the pile and reducing at the toe to a 3-foot length of $1\frac{1}{2}$-inch-diameter pipe with a $1\frac{1}{4}$-inch-diameter nozzle piece. The 2-inch-diameter pipe was recovered after jetting of the pile was completed.

Some of the working piles were selected from time to time for a check of their bearing by loading with a jack.

Fig. 13 (a)

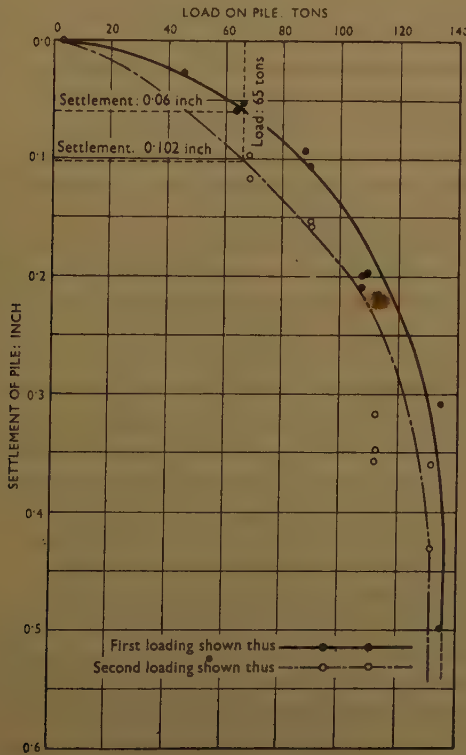


LOAD/TIME AND SETTLEMENT/TIME DIAGRAMS FOR TESTS ON PILE No. 4, KEADBY POWER STATION

Fig. 13 (*b*)

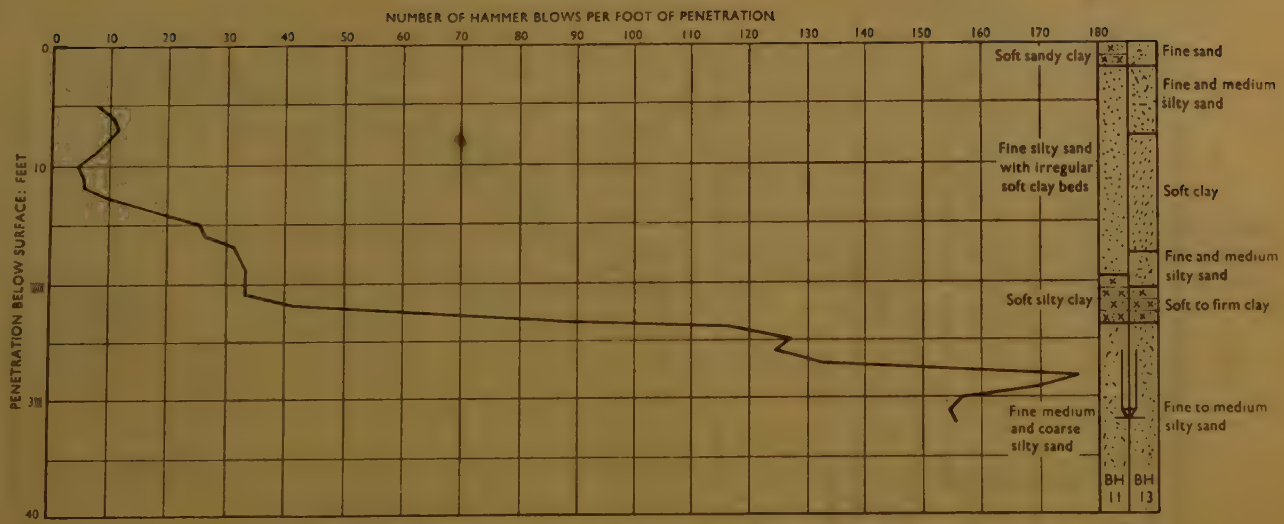
DETAILS OF TEST PILE

Size : 16 inches square, reinforced concrete, 35 feet long.
Reference number of pile from plan : T.P.4
Serial number of pile : 4. Nearest boreholes : Nos 11 and 13.
Date driven : 5 March, 1948. Date loaded : 13 March, 1948, and 9 April, 1948.
Driving characteristics :—Final penetration : 32 feet below ground level. Final set : 156 blows per foot, using 4-ton hammer with a fall of 3 feet. Weight of pile : 4·76 tons. Weight of helmet and dolly : 0·42 ton. Type of packing : sawdust and timber. Packing and dolly in loose condition at end of driving.
Type of kentledge : 10-cwt cast-iron blocks.
Note :—Load on pile of 3·3 tons, caused by dead weight of loading platform, included in test loads shown.



LOAD/SETTLEMENT DIAGRAM FOR TESTS ON PILE No. 4, KEADBY POWER STATION

Fig. 13 (c)



RECORD OF PILE DRIVING (PILE NO. 4), KEADBY POWER STATION
For details of test pile see *Fig. 13 (b)*, p. 55.

Doncaster Power Station

The Doncaster power-station site lies at Crimpsall, an island on the north-west side of Doncaster. The trial borings showed three distinct types of stratum: a top layer of silty clay, a middle layer of ballast, and a lower layer of red marl and sandstone. The average depth of each of the two top layers was about 20 feet. None of these strata is uniform in texture, and all contain water-bearing sand veins at random. In particular, the marl is traversed by irregular veins in both horizontal and vertical directions; the bedding of this marl is horizontal.

Four 15-inch-square precast reinforced-concrete piles were driven on this site, to a penetration of about 47 feet. One of these, at a point where a basin was shown by the borings to exist, was extended and redriven to 71 feet of penetration. No unduly hard driving was experienced with the test piles, as may be seen from the details given in Figs 16, Plate 2.

When piles for the main foundations were driven, conditions rapidly became harder, especially when penetrating the top third of the ballast layer. The time of driving was greatly reduced by the use of larger hammers, but the Authors feel that this was a case where jetting would have been advantageous, particularly since the ballast beds contained much sand. However, no jetting was done because the contractor elected to carry out all the pile driving with normal percussion methods. About 4,200 piles, each 50 feet long, have been driven on this site.

The nature of the plant to be supported on these piled foundations is such that no appreciable settlement could be tolerated once the plant is installed. The pile loading tests showed somewhat greater settlement than might have been expected. When driving piles in quantity the driving became easier after the top of the ballast had been penetrated. Hence, although the driving of the piles became difficult, it seemed essential to insist that the piles be driven into the marl rather than allow these to stop at a high level—as had been hoped possible in the initial stages of the scheme.

This case illustrates the remarks already made on the subject of the desirable weight for a hammer. At the suggestion of the Authors, the driving difficulties were largely overcome by the use of a single-acting steam hammer weighing about 4 tons.

Portishead "B" Power Station

The tests to be described were carried out in connexion with the construction of the Portishead "B" steam power-station, the site of which lies on the north-west side of the existing Portishead Dock in Somerset.

Between the site and the waters of the Severn estuary immediately to the north, some high ground rising to over 100 feet above sea level terminates in low rocky cliffs which generally follow the coastline. Broadly speaking, the surface stratum is of ashes with replaced Keuper marl, the latter in all probability having originally been taken from the excavations

for the existing dock. Below this made ground there are recent alluvial deposits overlying Keuper marl and triassic and old red sandstones.

Six 16-inch-square precast reinforced-concrete piles were driven and test-loaded together with two 12-inch-square solid prestressed concrete piles. All these piles were 50 feet in length. The prestressed piles were driven close to the normal piles so as to study the difference in behaviour under load for similar conditions. Figs 17 and 18, Plate 2, give the results of a typical pair from which it will be seen that, not unexpectedly, the penetration of the prestressed pile was smaller than the precast pile by about 2 feet. The total settlement under load was more than for the normal pile.

Little comment is necessary on the driving of the test piles, which was easy until the firmer stratum was reached at an average penetration of 30 feet.

Newport Alumina Factory

During the interval between the two world wars, a factory for producing alumina was constructed at Newport in Monmouthshire. The main columns together with certain of the heavier types of plant were founded on piles, but plain foundations were used for a number of large steel tanks. Some settlement of no consequence was expected and did, in fact, take place in the case of some of the tanks, but it was believed that this would occur only to a tolerable degree. However, these tanks contained caustic liquid and this fact gave rise to anxiety and entailed constant vigilance with regard to pipe connexions. It was, therefore, thought desirable to pile the foundations of these few tanks and this work was consequently put in hand. Owing to the existence of other plant in the vicinity it was not possible to move the tanks horizontally and they had to be lifted up about 10 feet before any work could be carried out. The tanks were situated inside a building and the headroom available was thus reduced and a bored type of pile was selected.

The ground consisted of about 40 feet of silt below the surface and overlying the Keuper marl. It was known that caustic soda existed in the groundwater because of leakage from the tanks, and concrete test cubes were made with samples of the groundwater; these cubes proved to be sound with a satisfactory strength.

The initial work of lifting one of the tanks was carried out without incident and the existing foundation was broken up. The first pile casing was then sunk in the normal manner and concreting was begun. However, with about two-thirds of the pile concreted it was found impossible to withdraw the tubes. A sample of the groundwater was therefore analysed and found to contain alkalinity equivalent to a 4-per-cent solution of sodium hydroxide, but mostly present as sodium aluminate and sodium carbonate; these last two compounds are intense accelerators of the setting of concrete, and also interfere seriously with the process of harden-

ing. This meant that the concrete at the lower end of the borehole had probably taken its initial set very quickly but had not hardened. This would not allow the tubes to be withdrawn without taking with them the concrete itself. The trouble was overcome by repeatedly flushing with clean water before concreting, using an airlock which was also employed during the concreting operation in order to exclude the groundwater. The casing was flushed by filling with water and then using compressed air to drive it out into the ground.

Jack loading tests were carried out on certain of the finished piles and *Fig. 19* shows one of these tests being made. The pile being tested is on the extreme left of the photograph underneath the jack. Two 18-inch-by-16-inch rolled steel joists acted as the lever arm, with two piles acting as anchors in the centre, and two further piles on the right of the picture taking the downward thrust. In order to reduce the uplift on the central piles the concrete yoke between them is loaded with a certain amount of kentledge.

Abadan Series of Tests

The following description is of work carried out on Abadan Island which extended over a period of about 5 years. The tests began after the Anglo-Iranian Oil Company had commissioned Messrs Foster Wheeler of London and New York to construct for them a new catalytic cracking unit. So far as the Authors are aware, bearing piles had been little used on the islands, but it was known that relatively large loaded areas, involving a unit pressure of more than about 7 cwt per square foot, could not be carried on raft foundations without appreciable settlement. Furthermore, the manufacturer of the plant had made it clear that parts of the new unit could tolerate little, if any, settlement of the foundations. For this reason they favoured the use of piles and the Authors' firm was asked to make an investigation of the site and recommend a safe working load for piles. In carrying out this work a great deal of valuable information relating to the soil conditions was supplied by Messrs Rendel, Palmer & Tritton, consulting engineers to the Anglo-Iranian Oil Company.

The record may conveniently be divided into two distinct parts. The first, or Stage 1, relates to the driving and loading of test piles on two selected sites; all the piles described in these tests were friction piles. The second part, called Stage 2, began when general settlement of a major order was reported. At that time, part of the foundations had been constructed and all the piles had been driven. The settlement continued over a period of 17 months. During constructional work pre-loading was carried out on the larger foundations with the object of accelerating the settlement so that the plant could be installed and put on load at an earlier date, kentledge being removed as erection proceeded.

It is understood that the plant has operated satisfactorily without any trouble arising in connexion with the foundations.

Stage 1.—Two sites were investigated on Abadan Island, situated about ½ mile apart, and on the north side of the Anglo-Iranian Oil Company's refinery. The two sites are referred to as site No. 1 and the S.P.A. site.

Both areas are practically flat, in common with the whole of the Island, the ground level of the two sites ranging between 39 and 40 feet above the Abadan datum. The general level of the desert is usually taken at 39·82 feet above this datum. The groundwater level ranges from 3 feet below ground to surface level and the sites are occasionally flooded.

Fig. 14, Plate 1, shows the location of the eight test piles driven on site No. 1. These were numbered T.P.G.1 to 4, and T.P.S.5 to 7, the former being driven and tested as a group and the latter singly. A further pile, T.P.G.5, was driven together with the group for use when carrying out uplift tests. Fig. 15, Plate 1, shows the S.P.A. site where twelve piles were driven, numbers D.1 to 4 being driven and tested as a group and the remainder, indicated by the letters A, B, C, E, I, J, K, and L, being single piles. This was the site eventually chosen for the erection of the new plant.

One of the first difficulties which arose was the question of finding a pile frame, since none existed in the locality. Finally a very old pile frame was imported. This was a 45-foot frame which was extended so as to be capable of driving a pile 55 feet in length, and by making a small excavation it was possible to pitch and drive a 60-foot pile. The frame was equipped with an oil-fired vertical-type boiler and steam-operated friction-winch; a 50-cwt cast-iron drop-hammer was used throughout, and a trigger release gear provided so as to give a free drop to the hammer when required. The heads of the piles were protected during driving by a fabricated mild-steel helmet, used in conjunction with a hardwood dolly, hessian packing being inserted between the helmet and the pile head.

The piles were of pre-cast reinforced concrete and were 14 inches square in cross-section; on site No. 1 they were 50 feet in length except for T.P.S.6 which was 60 feet long. At the S.P.A. site the piles forming the group D.1 to 4 were 50 feet in length, the remainder being 60 feet long. In the case of the first sixteen piles driven, rapid-hardening portland cement was used, ordinary portland cement being used for the remaining four.

The piles were in general driven by lifting the hammer by means of the steam winch and letting it fall by declutching; the bond was permanently attached to the hammer so that the winch drum was overhauled at each stroke. However, at intervals during the driving the free release trigger was used for obtaining a set with an entirely free drop of the hammer. All final sets were taken in this way so as to have an accurate record of the energy of the hammer for estimating the driving resistance by formulae. Records of the set per blow were made throughout the driving of each pile together with measurement of the temporary compression. (See Table 1, Plate 4).

In order to apply the test load to a single pile, a built-up mild-steel cap was fitted to the head, surmounted by two steel plates 10 feet by 5 feet

by 1 inch thick, after which was added the kentledge consisting of packets of mild-steel drum plate each weighing nearly 2 tons.

In the case of the pile groups, a mild-steel cap was applied, surmounted by a grillage of 30-foot lengths of flat-bottom rails and 6-inch-diameter screw-pile bars, additional load being provided by means of packets of drum plate. These packets of thin steel plate were the only suitable kentledge available and formed the greater part of the load in each case. This form of kentledge was not particularly suitable and it had been hoped that sufficient pile bars would be available. In the case of the single piles it was found difficult to maintain the centre of gravity of the whole load correctly on the axis of the pile and this contributed towards the failure of the head which occurred in two cases.

Settlement of the piles was measured directly from a mild-steel angle supported by stakes driven into the ground well clear of the pile. Records of load and settlement were made and related to the elapsed time from the commencement of the test. (See Table 1, Plate 4.)

The piles forming the groups showed unequal settlement under load. The effect of this was aggravated by the high centre of gravity of the kentledge which resulted in unequal distribution of load. *Fig. 20* shows a group of four piles being loaded, and *Figs 11* and *21* show one of these tests after failure. Results of one of the group-loading tests are given in Appendix II, Table 3.

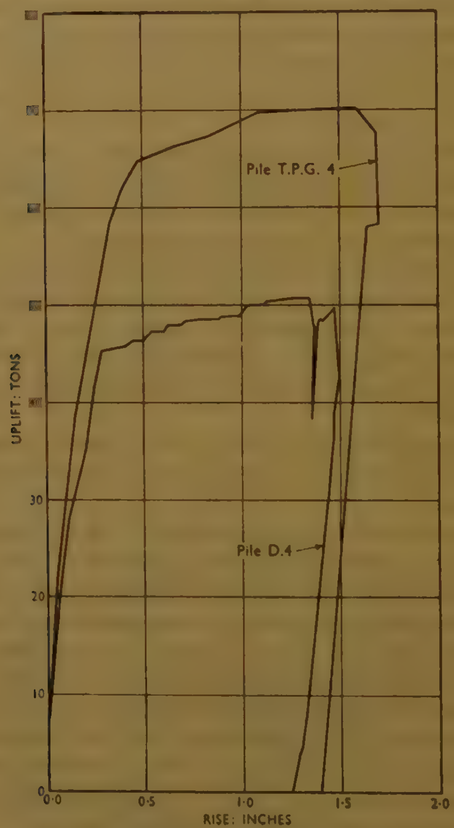
The piles were loaded at least twice in each case, with varying intervals of time between the two tests. In some cases three loadings were made and in one case four.

In order to obtain an accurate measure of the frictional resistance of the piles, uplift tests were carried out on pile T.P.G.4 at site No. 1 and on pile D.4 at the S.P.A. site. In each case this was effected by means of a 100-ton hydraulic jack, fitted with a pressure gauge, acting through a 24-inch-by-7½-inch rolled steel joist forming a lever, the mechanical advantage thus provided being approximately 2. In these tests a continuous record was made of the rise of the pile and the force applied. So far as possible, the rate of application of load was kept constant. The results of these tests (see Appendix II, Table 4) indicated an end-bearing load of about 10 tons per pile. *Fig. 22* shows the plot of some typical results of the tests, whilst *Fig. 23* shows a test in progress.

An opportunity was provided of examining the soil investigation results previously obtained from borings taken over the areas investigated, through the courtesy of Messrs Rendel, Palmer & Tritton. These results could not readily be compared with those of the pile tests since the shear strength of the ground revealed from the samples taken varied considerably from depth to depth in the same borehole. The most that can be said is that the average shear strength appeared to be about 400 lb. per square foot and this figure conformed reasonably well with the observed uplift measurements.

Eleven of the piles were provided with metal shoes and nine were driven with the point formed in concrete, the length of the toe from the point to the full section of the pile being 18 inches with a $1\frac{1}{2}$-inch chamfer at the arris. At the No. 1 site an attempt was made to withdraw one of these piles by means of a mast derrick and a five-sheave-block tackle, the

Fig. 22



UPLIFT TESTS, ABADAN

fall being taken to a mechanical navvy and pulled away by traversing the latter. It was not found possible to do this sufficiently smoothly, with the result that the attempt failed owing to the reinforcing bars being pulled out and the top of the pile broken.

At the S.P.A. site, pile D.1 was successfully extracted by jacks. The object of this extraction was to see whether any damage had been done to the toe of the pile during driving and, in fact, none was found; this saved

a small amount of money in the case of the piles driven later. It is interesting to note that a skin of soil approximately 1 inch thick remained on the pile after extraction (see *Fig. 24*).

The results of the loading tests were found to be generally consistent, although there was some variation in behaviour between individual piles. In Table 1, Plate 4, a complete summary is given of the information obtained during driving and test loading. Appendix II, Table 5, gives a typical loading sheet.

Two points of interest are worth noting: first, the driving resistance as calculated from formulae, compared with the actual failure load obtained; secondly, the failure load of the four-pile groups amounted to approximately four times the failure load of a single pile.

Following these results a recommendation was given that a load of 20 tons per pile might be adopted for groups of piles, provided that they were driven at centres of not less than 4 feet by 4 feet or 5 feet by 3 feet, but a reservation was given that this applied to groups of up to sixteen piles. The size of pile given was 14 inches square by 60 feet long and the allowable load was exclusive of the weight of the pile itself.

Stage 2.—The second stage of the project began about 2 years later, when the foundations had been designed and partly constructed, and some unexpected settlement was reported. During this intervening period the design of the catalytic cracking plant had been completed, and the construction of the foundations for this plant also was well advanced. These foundations were situated on the S.P.A. site where all the 1,074 piles for the foundations had been driven. These piles were all of reinforced concrete, 15 inches square and 60 feet long.

Figs 25, Plate 3, show the area of the catalytic cracking plant as well as the location of the various points which had been established for the purpose of recording settlement. The shaded areas indicate where the pile caps had already been cast. The positions of pits for recording water level in the trial boreholes, the single pile subject to jack loading tests, and other relevant data are also shown in Figs 25. The position of a large pump-house which was being constructed on the south side of the catalytic cracker area is also shown, because at the time it was suspected that the drawing of water and possibly soil from the excavation for this structure might have been the cause of the settlement.

In *Fig. 26* is shown the progress of the construction of the catalytic cracking plant and pump-house foundations together with certain selected settlement records. Appendix I gives the results of the jack loading tests on a single pile.

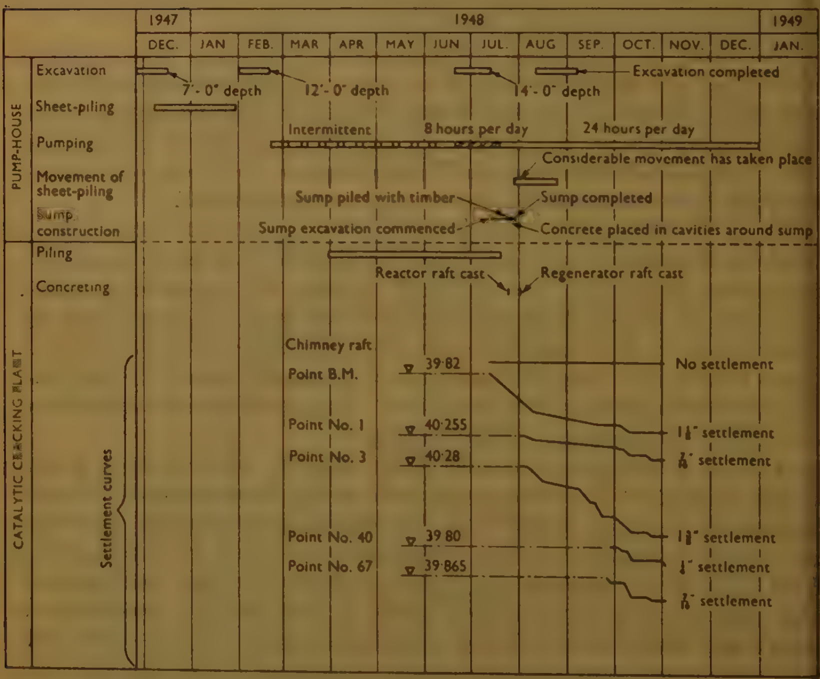
At this time the maximum settlement so far recorded had been of the order of $1\frac{3}{8}$ inch and various reasons had been put forward to account for the downward movement of the piled foundations under practically no load other than their own weight.

Of the possible causes, two were discounted; these were seismic action

or a general variation in the shear strength of the soil. The causes considered possible were either reconsolidation of the ground following disturbance due to piling or the above-mentioned effect of consolidation following the removal of soil and/or water during the construction of the pump-house. Further, at this time the following facts had been established:

(1) The chimney foundation, supported by twenty-five piles, had not moved. This structure is situated on the north-west side of the area.

Fig. 26



TIME RELATION OF CONSTRUCTION WORK TO SETTLEMENT OF PILED FOUNDATIONS AT ABADAN

(2) Where records existed and within the limits of accuracy of normal levelling ($\pm \frac{1}{8}$ inch), all other piled foundations appeared to have subsided fairly evenly and by amounts related to the period of observation.

(3) Jack loading tests on a single pile were taken far enough to remove doubts as to the shear value of the soil (see Appendix I).

(4) The invert levels of thirty-nine pipes set in drainage manholes around the periphery of the reactor-regenerator foundation

Fig. 1

Test Pile being Driven using Trigger Release Mechanism

Fig. 2

Measurement of Temporary Compression

Fig. 3

Fig. 4

False Leaders in use for Driving Piles

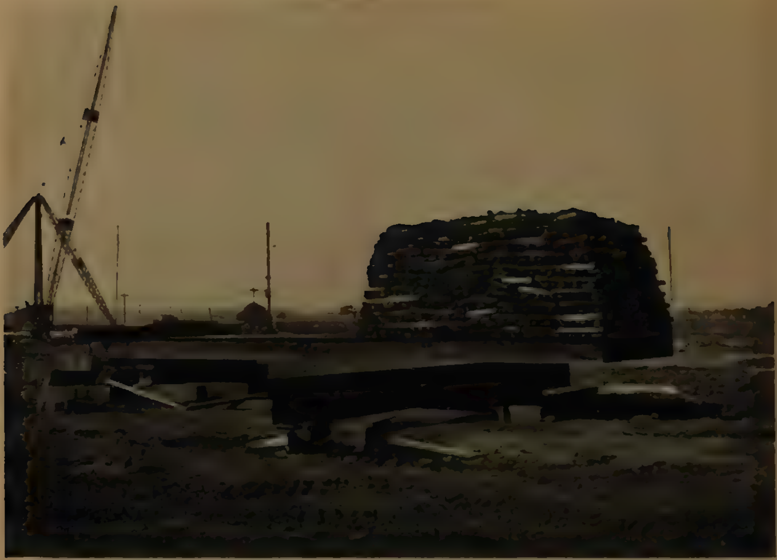
Fig. 5

Jack Loading Test using Four Piles to take Upthrust

Fig. 6

Simple Loading Platform and Kentledge

Fig. 8



STABILIZED PLATFORM IN USE DURING A LOADING TEST

Fig. 9

JACK BEING USED BETWEEN PILE AND PLATFORM FOR WEIGHING LOAD

Fig 10

STABLIZED PLATFORM IN USE DURING LOADING TEST

Fig. 11

FOUR-PILE GROUP LOADING TEST AFTER FAILURE, SHOWING THE METHOD OF MEASURING THE SETTLEMENT

Fig. 19

JACK LOADING TEST IN PROGRESS

Fig. 20

FOUR-PILE LOADING TEST IN PROGRESS

Fig. 21

FOUR-PILE LOADING TEST AFTER FAILURE

Fig. 23

Uplift Test on Central Pile in Progress

Fig. 24

Toe of Pile after Extraction, showing Skin of Soil left on Sides of Pile

were now consistently below the theoretical levels at which they should have been set, by an average of $1\frac{1}{2}$ inches. These manholes ranged in depth from 4 to 12 feet.

(5) In connexion with the construction of the pump-house it was noted that the sheet-piling cofferdam was only 20 feet in depth; there had been inward movement of this piling of up to 2 feet 2 inches on the north side. There was no clear evidence that the quantity of material excavated was not much greater than the net measurement.

(6) The surface-water table did not appear to have been materially affected by the work on the pump-house.

A suggested limit of ground disturbance caused by piling is shown on Figs 25, Plate 3, although outside this limit setting-out point No. 102 was suspected of having risen very slightly.

At the time, the excavation in the pump-house appeared to have some connexion with the settlement of the catalytic cracking plant, but since this settlement continued over a long period after the pump-house was finished, it seemed less likely that any relation between the two structures could be deduced, but it will be seen from *Fig. 26* that the timing of the construction of the two structures could readily be linked. Moreover, some local disturbance could be expected from the driving of the chimney piles. Thus, if the reason for the settlement had been reconsolidation following disturbance caused by piling, some settlement of the chimney foundation might have been expected, but none was recorded.

Again, this foundation was furthest away from the pump-house and would thus be least affected, if settlement was attributable to the pump-house construction. Another point was that, during the period of test piling, reconsolidation around piles took 1 to 2 months, whereas subsidence still continued $5\frac{1}{2}$ months after the last pile was driven for the reactor-regenerator foundations.

Settlement took place soon after excavation for the pump-house had reached full depth and 24-hour pumping had begun. The surface-water table did not appear to have been affected, which might have meant that the water reaching the pump-house excavation came primarily from the weaker ground known to underlie the stronger stratum existing between 17 and 23 feet below the surface. Attempts were even made to trace a connexion between the two structures by injecting aniline dye at the catalytic cracking plant, but without any positive results.

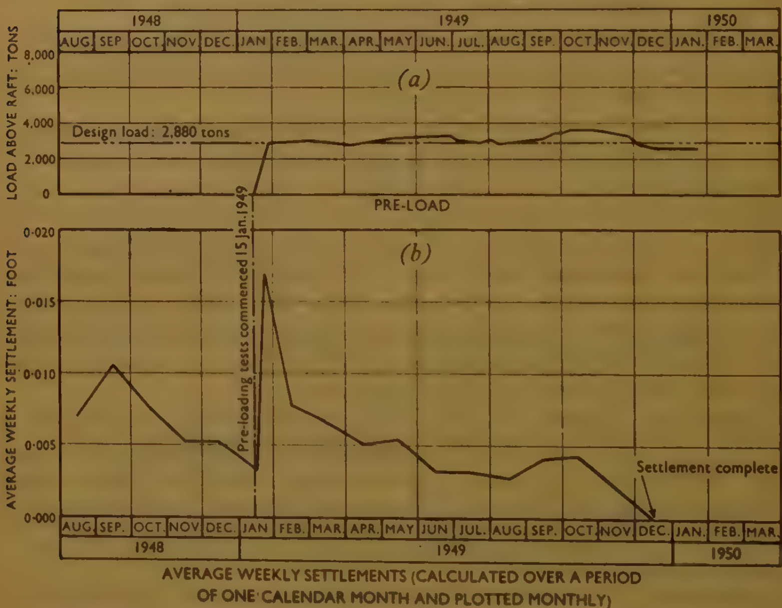
Settlement continued steadily and to enable the plant to be completed to schedule it was decided to pre-load certain of the major foundations with the object of accelerating the stabilizing of the foundations.

The pre-loading was effected by applying 20 per cent more than the designed load with packets of drum plate. As construction of the superstructure proceeded, the load was kept constant by gradually removing the kentledge.

Settlement readings were taken daily and plotted against time. From these results weekly averages were deduced and plotted as shown in *Figs 27*, which relates to the largest piled raft, comprising 272 piles. From this graph it can be seen that the incidence of the pre-load certainly accelerated the movement as intended.

Settlement took place over a period of 17 months and was not limited to the piled structures. The whole area subsided and *Fig. 28* illustrates quantitatively the total settlement recorded. As might be expected the

Fig. 27



RATE OF SETTLEMENT OF REGENERATOR RAFT (PILE GROUP No. 18), No. 1 CATALYTIC CRACKING UNIT, ABADAN

maximum, amounting to 4½ inches, occurrred roughly at the centre of the heavily piled area.

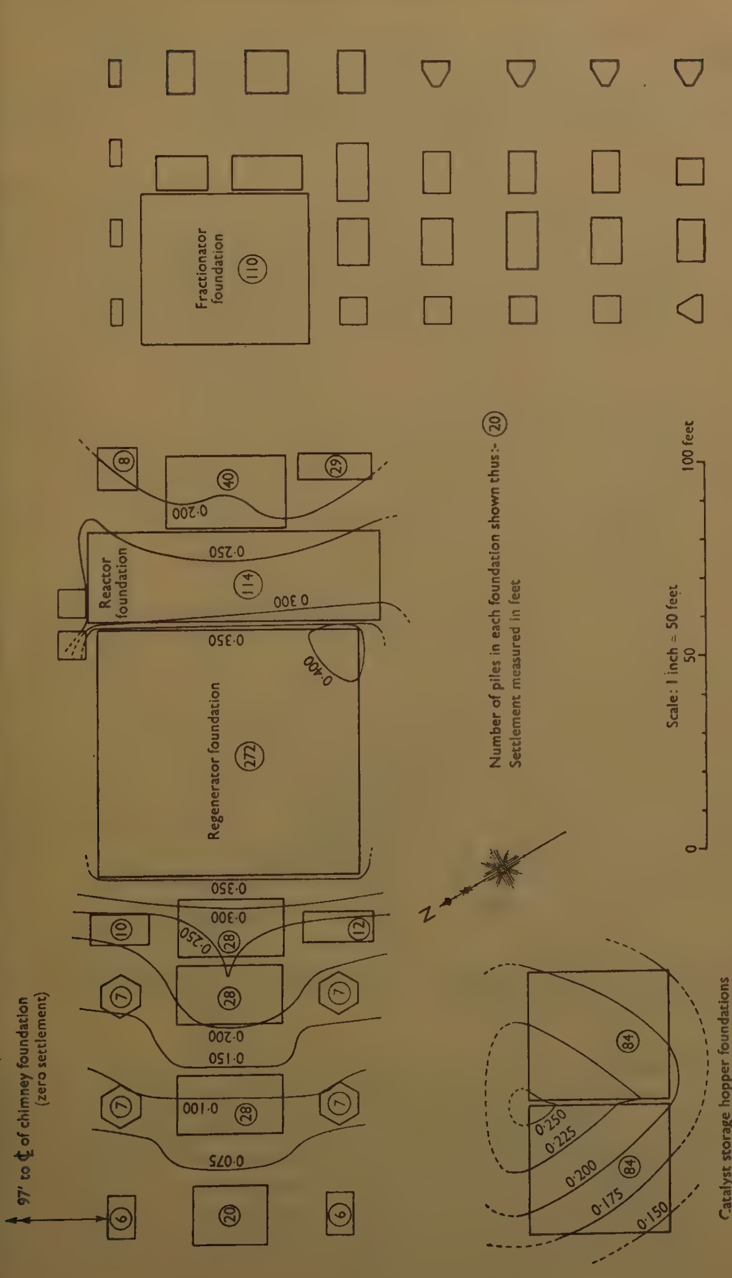
The plant itself was successfully brought into operation early in 1951.

SOME POINTS ON DESIGN

Suspension Points

The maximum bending moments induced when piles were being lifted are plotted on *Fig. 29* against one, two, three, four, and five points of suspension and are given for equal vertical reactions such as are obtained approximately in practice by the use of a running rope. It is not considered to be advisable to use fixed ropes for anything more than two

Fig. 28

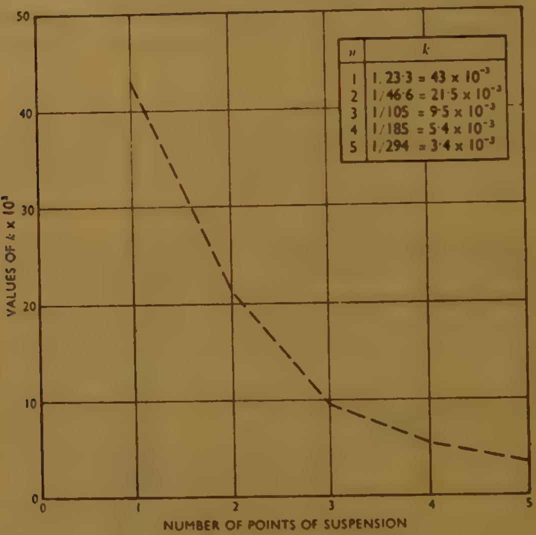


Final Lines of Equal Settlement of Foundations of Catalytic Cracking Unit, Abadan

points of suspension because the true bending moments will be affected adversely by any unequal displacement at the points of support.

It is general practice to use only two points of support but it will be seen from the graph that there is a great advantage in using more than

Fig. 29



$$M = kwL^2$$

where M denotes bending moment.
w ,, weight per unit length of pile.
L ,, length of pile.
k ,, multiplying factor.
n ,, number of points of suspension.

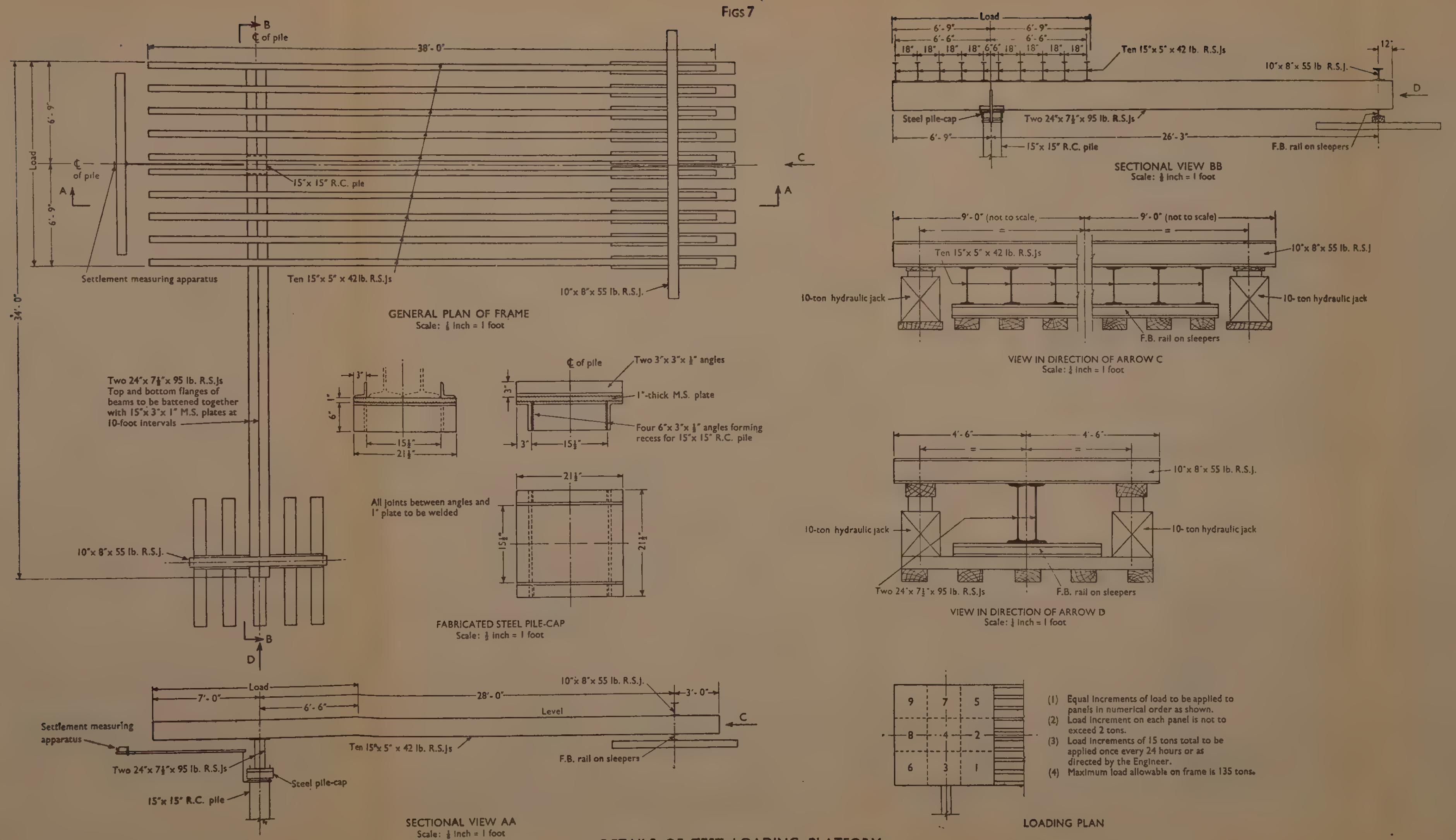
MAXIMUM BENDING MOMENTS IN A PILE DUE TO LIFTING

two points of suspension, though the relative advantage decreases rapidly with more than four points.

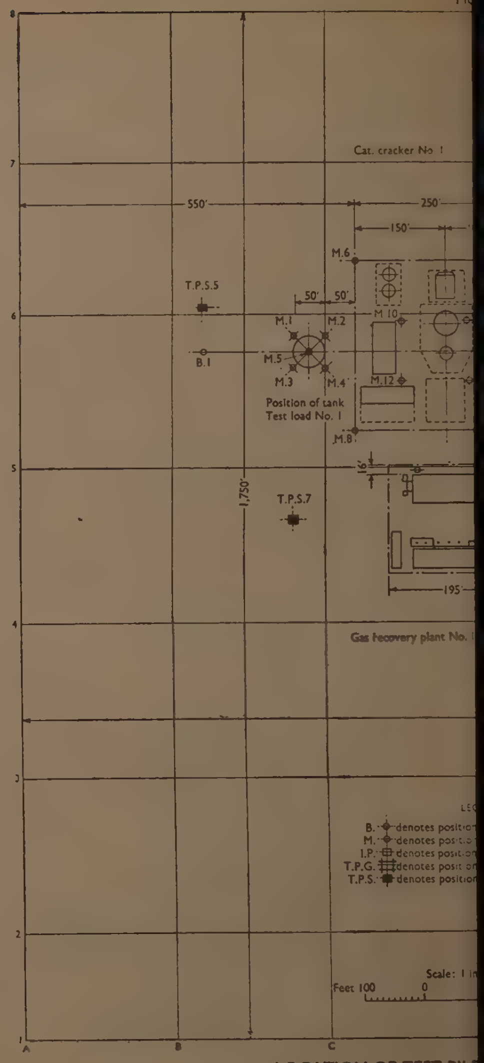
Main Reinforcement

The longitudinal reinforcement in precast concrete piles has three functions to perform. These are to limit the stresses induced first during handling and pitching, secondly during driving, and finally in carrying the working load. The Authors feel that a great deal of steel has been and indeed is still being wasted because insufficient attention is paid to these points. In the past, this has probably been attributable to the abundance of steel in Great Britain and also to the difficulty of rational analysis of stresses during driving. This has led to the adoption, as it were, of a standard practice based on past usage.

FIGS 7



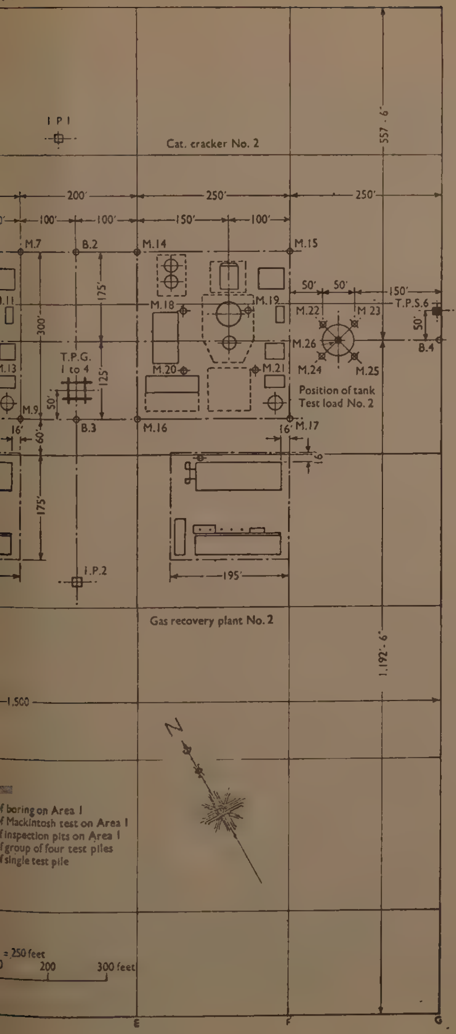
DETAILS OF TEST LOADING PLATFORM



LOCATION OF TEST PILE

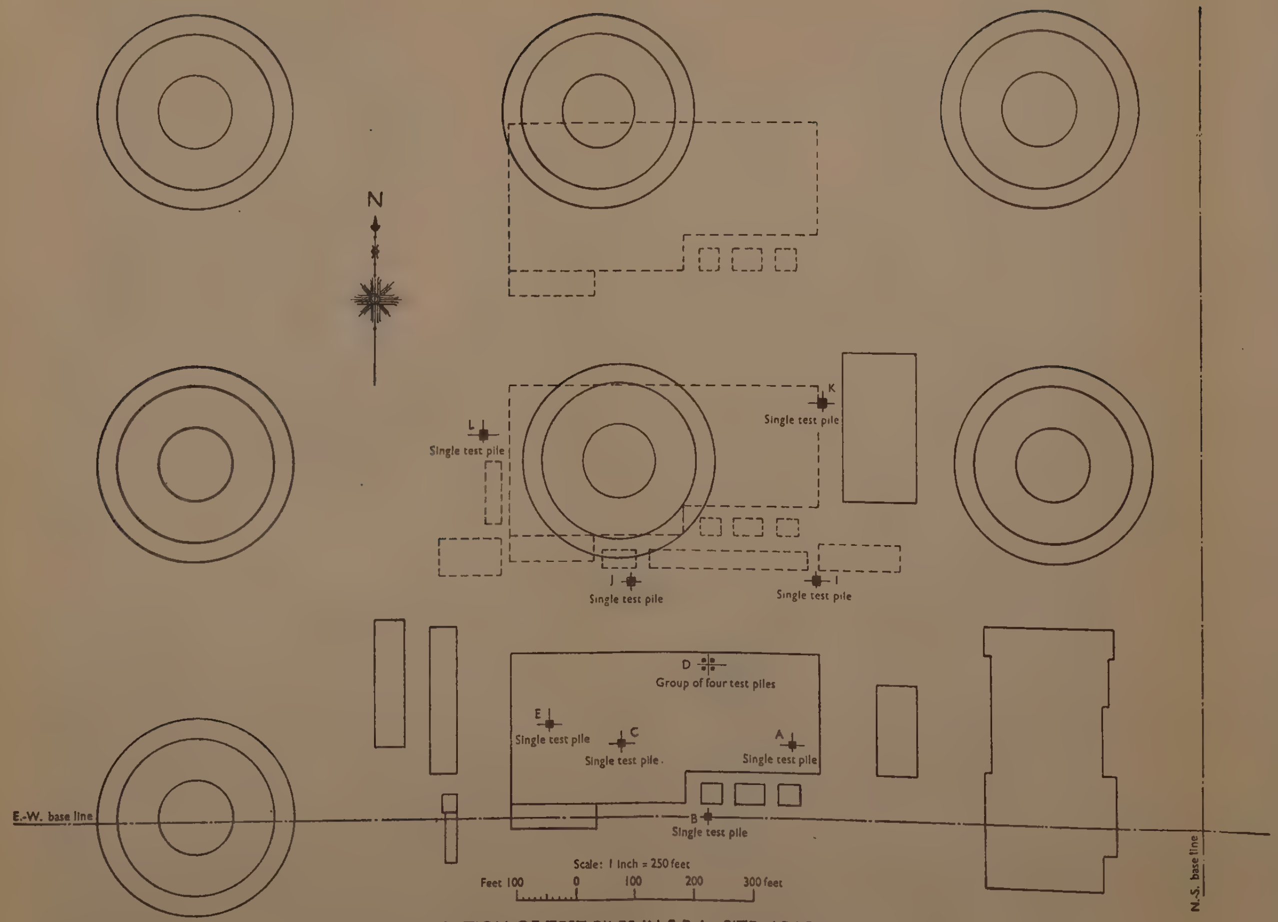
The Institution of Civil Engineers.

14



IN SITE No. 1, ABADAN

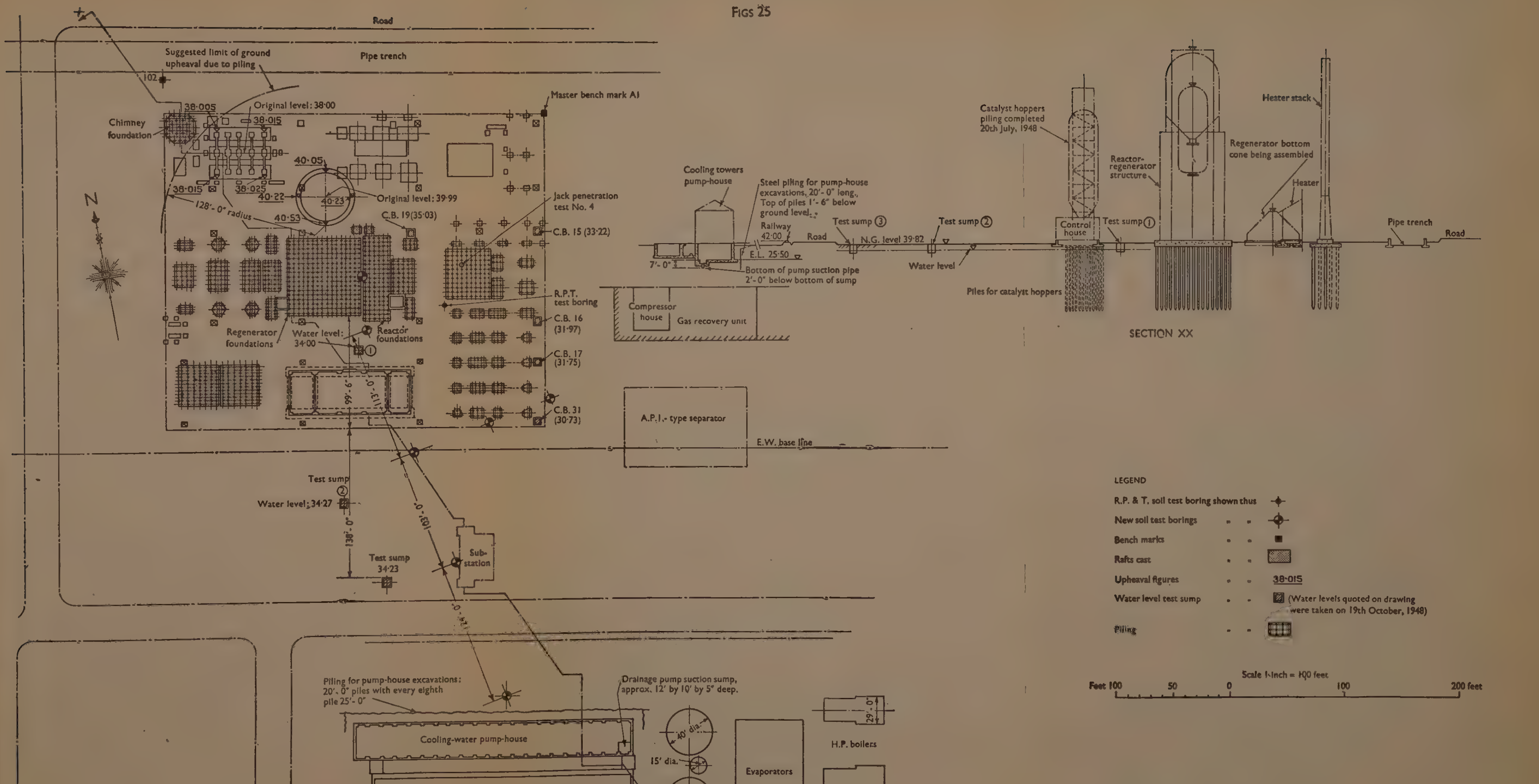
Fig. 15



LOCATION OF TEST PILES IN S.P.A. SITE, ABADAN

H. D. MORGAN and C. K. HASWELL

FIGS 25



GENERAL LAY-OUT OF FOUNDATIONS FOR
No. 1 CATALYTIC CRACKER UNIT AND PUMP-HOUSE, ABADAN

THE DRIVING AND TESTING OF PILES

TABLE 1.—DATA ON THE DRIVING AND LOADING OF TEST PILES AT ABADAN FOR NEW CATALYTIC CRACKING PLANT

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
						Hiley		E.N.R.	On redrive							1st Loading			2nd Loading			Settlement details					
													Hiley		E.N.R.		Failure load: tons			Failure load: tons		1st loading		2nd loading		3rd loading	
Site	Pile Number	Length of pile: feet	Final set: inches per blow	Free drop: inches	Temp. compn: inches	Estimated driving resistance: tons	Estimated driving resistance using measured temp. compn: tons	Estimated driving resistance: tons	Time interval: hours	Set: inches per blow	Free drop: inches	Temp. compn: inches	Estimated driving resistance: tons	Estimated driving resistance using measured temp. compn: tons	Estimated driving resistance: tons	Days after driving	greater than	less than	Days after driving	greater than	less than	Tons	Settlement: inches	Tons	Settlement: inch	Tons	Settlement: inch
No. 1	T.P.G.3	50	0·97 1·17	36 48	— —	31·7 34·9	— —	12·6 14·5																			
	P.T.G.4	50	0·66 0·78	36 48	— —	41·8 48·0	— —	17·2 20·2								15	201·91	—	44	266·51	279·74	81·88 104·25	0·08 0·13	81·62 123·15	0·05 0·06		
	T.P.G.1	50	1·05 —	36 —	— —	29·5 —	— —	11·9																			
	T.P.G.2	50	0·75 —	36 —	0·20 —	38·5 —	38·0 —	15·6																			
	T.P.S.7	50	0·87 1·10	36 48	— —	34·5 36·8	— —	13·9 15·3	42	0·32	36		62·5		28·3	13	42·43	49·97	31	49·97	51·88	19·60 25·30	0·10 0·15	— 25·08	— 0·12		
	T.P.S.5	50	— 0·70	— 48	— —	— 52·2	— —	22·0								11	46·29	—	43	44·39	48·21	19·53 25·32	0·16 0·22	13·96 21·52	0·04 0·09	25·33	0·10
	T.P.S.6	60	0·85 1·12	36 48	0·44 0·41	32·5 34·0	28·0 31·8	13·9 14·8	16	0·38	36		53·3		24·6	20	63·00	66·84	30	55·38	59·22	21·21 28·93	0·07 0·10	— 28·79	— 0·10		
S.P.A.	D.1	50	1·17 1·44	36 48	— 0·42	27·0 30·0	— 28·0	10·9 12·1	16·5 196·25	0·41 0·09	36 36	 0·25	55·5 83·5	 96·5	24·2 50·0												
	D.2	50	0·25* 0·37*	36 48	— 0·33	64·2* 71·3*	— 71·7*	32·6 34·5								32	210·89	239·02	43	182·53	220·03	88·44 125·94	0·09 0·16	51·05 107·53	0·03 0·07		
	D.3	50	0·93 1·12	36 48	— 0·39	32·8 36·2	— —	13·1 15·0	45·5	0·36	36		59·2		26·4												
	D.4	50	0·81 0·98	36 48	0·39 0·49	36·3 40·0	33·2 35·7	14·7 16·8																			
	B	60	0·81 0·95	36 48	0·51 0·49	33·5 38·0	28·0 33·2	14·4 16·9								19	58·64	62·39	36	58·64	62·39	21·11 28·61	0·09 0·16	— 24·81	— 0·08		
	A	60	1·21 —	36 —	— —	24·3 —	— —	10·4								13	51·06	52·93	28	54·82	58·63	21·06 28·56	0·17 0·23	13·56 24·81	0·04 0·08	24·81	0·04
	C	60	0·75 0·90	36 48	0·67 0·68	35·4 39·4	28·0 32·2	15·3 17·7	48	0·54	36		43·9		19·5	16	62·56	66·31	35	51·08	—	21·08 28·65	0·10 0·18	— 24·85	— 0·05		
	E	60	0·74 0·91	36 48	0·66 0·63	35·8 39·3	28·0 33·2	15·5 17·8	119	0·25	33		63·0		31·3	30	62·31	66·06	—	—	—	21·01 28·50	0·07 0·10	— —	— —		
	I	60	0·60 —	36 —	— —	41·0 —	— —	18·1								8	43·85	51·46	18	47·70	51·50	21·25 28·74	0·15 0·25	— 25·00	— 0·06		
	J	60	0·47 0·18	36 18	0·42 0·35	47·5 44·0	41·9 38·1	21·4 18·3								11	43·97	51·55	22	51·22	54·97	21·14 28·85	0·10 0·18	24·89 32·47	0·08 0·09		
	K	60	0·62 0·20	36 18	— —	40·3 42·5	— —	17·6 17·5								8	43·71	51·26	29	55·26	59·05	21·26 28·89	0·22 0·36	24·94 36·30	0·04 0·09		
	L	60	0·79	36	0·60	34·2	28·1	14·7								12	62·58	66·39	—	—	—	21·12 28·71	0·09 0·12	— —	— —		

* Partial redrive

The operations of handling and pitching piles are all too often carried out by using a two-point suspension. Reverting to the graph mentioned above (*Fig. 29*), it will be seen that, by employing a three-point suspension, the maximum bending moment becomes less than half that obtained with a two-point suspension. Hence, good use may be made of the three-point lift where the handling and pitching bending-moments are the main criteria.

The advantages of the four- and five-point lifts are not generally sufficient to warrant the use of the more complicated lifting gear except in the case of abnormally long piles.

It should be emphasized that, for design purposes, handling and pitching are considered together. For example, the Authors do not consider it rational to use a three-point lift from the pile bed and then only a two-point lift whilst pitching the pile, although of course, the concrete is more mature when pitching for driving than when lifting the pile off the bed. Nevertheless, this procedure is often used in order to free the pile-casting bed earlier.

The reinforcement necessary for driving is a matter of greater controversy. It is here that a wise assessment has to be made of the difficulties experienced when driving the test piles. No hard and fast rules for design can be laid down, but in many cases, for example where piles can be jetted successfully, the reinforcement required for driving is of secondary importance.

The longitudinal reinforcement in a pile for load-bearing purposes is rarely a deciding factor. Provision has to be made, of course, for the minimum requirements for the pile acting as a column.

Acknowledgements

The Authors wish to express their thanks to Mr V. A. Pask, M.I.E.E., M.I.Mech.E., Chief Engineer of the British Electricity Authority; the Anglo-Iranian Oil Company; the British Aluminium Company; and Foster Wheeler Ltd., for permission to publish results of tests carried out in connexion with works undertaken by them.

The Paper is accompanied by fifteen photographs and fifteen sheets of drawings, from which the half-tone page plates, folding Plates 1, 2, 3, and 4, and the Figures in the text have been prepared, and by the following two Appendices.

APPENDIX I

Jack Loading Test of Single Pile

Date	Time	Load: tons	Settlement: inch
1. 30-*ton Test Load*			
20 October, 1948	0935	0	0·0
„ „	0940	30	0·020
„ „	0950	30	0·025
„ „	1140	30	0·035
21 October, 1948	0940	30	0·035
„ „	0940	0	0·018
22 October, 1948	0940	0	0·010
2. 50-*ton Test Load*			
23 October, 1948	0810	0	0·0
„ „	0815	5	Not taken
„ „	0825	10	Not taken
„ „	0835	15	0·010
„ „	0845	20	Not taken
„ „	0855	25	0·015
„ „	0905	30	0·020
„ „	0915	35	0·025
„ „	0925	40	0·030
„ „	0935	45	0·040
„ „	0945	50	0·050
„ „	1030	50	0·060
„ „	1130	50	0·075
„ „	1230	50	0·075
„ „	1330	50	0·075
„ „	1630	50	0·075
„ „	2030	50	0·085
„ „	2400	50	0·085
24 October, 1948	0730	50	0·105
„ „	0815	50	0·105
„ „	0900	0	0·063
25 October, 1948	0730	0	0·045

APPENDIX II

The following Tables relate to pile-driving, loading, and uplift tests carried out on the site for the new catalytic cracking plant at Abadan. The piles in each case were of reinforced concrete, 14 inches square in cross-section.

TABLE 2.—PILE-DRIVING RECORD

(The readings are tabulated on p. 72)

Details of pile.—Serial No. 12. Reference No. on pile plan: T.P.S.6. Weight: 5·47 tons. Length: 60 feet. Construction: reinforced concrete, using rapid-hardening cement. Date cast: 30.10.45.

Details of driving.—Type of hammer: 50-cwt drop-hammer. Type of packing on pile head: 4 inches of hessian. Weight of helmet and dolly: 0·24 ton. Condition of packing and dolly: good. Nearest borehole: B.4. Date of driving: 21.11.45.

Ground level above datum: 40·4 feet. Depth of excavation for pitching: 3 feet.

Penetration from ground level after pitching: 4 feet 9 inches.

TABLE 3.—RECORD OF LOADING TEST ON PILE GROUP

(The readings are tabulated on p. 73)

Details of piles.—Serial Nos 11, 8, 9, 10. Reference Nos on pile plan: Group D, Nos D.1 to 4. Number and spacing of piles: four at 5-foot centres (square). Length: 50 feet. Construction: reinforced concrete, using rapid-hardening cement. Dates cast: 25th, 22nd, 23rd, and 23rd October, 1945. Dates driven: 2nd, 3rd, 5th, and 9th December, 1945.

Ground level above datum: 39 feet. Penetration: 47 feet. Nearest borehole: B.4.

TABLE 4.—RECORD OF UPLIFT TEST

(The readings are tabulated on p. 74)

Details of pile.—Serial No. 10. Reference No. on pile plan: D.4. Length: 50 feet. Construction: reinforced concrete. Date cast: 23.10.45. Date driven: 9.12.45. Dates loaded: 3/16.1.46 and 17/23.1.45.

Ground level above datum: 39 feet. Penetration: 47 feet.

Nearest borehole: B.4. Date of uplift test: 12.2.46.

TABLE 5.—RECORD OF SINGLE-PILE LOADING TEST

(The readings are tabulated on p. 75)

Details of pile.—Serial No. 20. Reference No. on pile plan: K. Length: 60 feet. Construction: reinforced concrete. Date cast: 20.12.45. Date driven: 28.2.46 1.3.46

Ground level above datum: 39·6 feet. Penetration: 57 feet. Type of kentledge used for loading: M.S. cap; two M.S. plates, each measuring 10 feet by 5 feet by 1 inch; packets of M.S. drum plate.

TABLE 2. (*See p.* 71)

Penetration below ground level : feet	Number of blows per foot	Set : inch per blow	Measured temporary compression : inch	Drop of hammer : feet		Penetration below ground level : feet	Number of blows per foot	Set : inch per blow	Measured temporary compression : inch	Drop of hammer : feet	
				Using monkey-trigger	Using friction winch					Using monkey-trigger	Using friction winch
1						36	23				1·5
2						37	22				,,
3						38	19				,,
4						39	24				,,
5						40	21	0·99	0·34		3·0
6	7				1·0	41	24				1·5
7	10				,,	42	23				,,
8	9				,,	43	23				,,
9	11				,,	44	24				,,
10	11				,,	45	23	0·93	0·39		3·0
11	16				,,	46	33				1·5
12	13				,,	47	35				,,
13	11				,,	48	38				,,
14	10				,,	49	36				,,
15	11				,,	50	41	1·12	0·32	3·0	
16	26				,,	51	29			1·5	
17	35				,,	52	33			,,	
18	37				,,	53	35			,,	
19	48				,,	54	45			,,	
20	56	0·44			3·0	55	39	0·85	0·44	3·0	
21	45				1·5	56	39	1·10	0·41	4·0	
22	40				,,	57		1·14		4·0	
23	32				,,	58					
24	29				,,	59					
25	24				,,	60					
26	29				,,	61					
27	51	0·50			3·0	62					
28	47				1·5	63					
29	36				,,	64					
30	30	0·58	0·39		3·0	65					
31	47				1·5	66					
32	33				,,	67					
33	26				,,	68					
34	19				,,	69					
35	22	1·00	0·21		3·0	70					

TABLE 2 (*a*).—RE-DRIVING TESTS

Date: 22.11.45

Penetration : feet	Time interval : hours	Set per blow : inch	Drop of hammer : feet
57	16	0·38	3 (using monkey-trigger)

TABLE 3. (*See p.* 71)

Date	Time	Load on : tons	Load off : tons	Total load : tons	Settlement : inch D.1	D.2	D.3	D.4	Average	Type of kentledge
3.1.46	1000	2·44		2·44						Double cap F.B. rails (50 lb. per yard)
,,	1000–1600	11·05		13·49						
,,	1610				0	0	0	0	0	
4.1.46	0800				0	0	0	0	0	
,,	1000–1430	37·45		50·94						Rails and M.S. sheets.
,,	1435				0·01	0·03	0·03	0·03	0·03	
5.1.46	0945				0·02	0·04	0·04	0·04	0·04	
,,	0945–1230	37·50		88·44						M.S. sheets
,,	1230				0·04	0·08	0·07	0·08	0·07	
6.1.46	1220				0·07	0·10	0·09	0·10	0·09	
,,	1220–1330	37·50		125·94						M.S. Sheets
,,	1335				0·10	0·12	0·11	0·13	0·11	
7.1.46	1215				0·13	0·16	0·17	0·20	0·16	
,,	1215–1330	28·13		154·07						M.S. sheets
,,	1330				0·17	0·20	0·20	0·22	0·20	
8.1.46	0840				0·20	0·23	0·24	0·29	0·24	
,,	1510				0·20	0·23	0·25	0·29	0·24	
,,	1510–1550	28·43		182·50						M.S. sheets
,,	1550				0·22	0·30	0·28	0·32	0·28	
9.1.46	0930				0·30	0·35	0·35	0·40	0·35	
,,	0935–1020	28·39		210·89						M.S. sheets
,,	1020				0·34	0·39	0·39	0·45	0·39	
,,	1505				0·40	0·45	0·45	0·53	0·46	
10.1.46	0805				0·48	0·50	0·51	0·60	0·52	
,,	0805–0925	28·13		239·02						M.S. sheets
,,	0925				0·56	0·58	0·59	0·67	0·60	
,,	1300				0·77	1·00	0·70	0·82	0·82	
,,	1405				0·80	1·01	0·72	0·85	0·85	
,,	1435				0·83	1·04	0·72	0·85	0·86	
11.1.46	0845				1·43	1·64	0·85	0·98	1·23	
,,	0845–1050		37·59	201·43						M.S. sheets
,,	1050				1·43	1·64	0·85	0·98	1·23	
,,	1415				1·43	1·64	0·84	0·97	1·22	
12.1.46	0815				1·42	1·64	0·84	0·97	1·22	
,,	0825–0930		37·68	163·75						M.S. sheets
,,	0935				1·41	1·63	0·82	0·96	1·21	
,,	1545				1·41	1·62	0·82	0·96	1·20	
13.1.46	0845				1·40	1·61	0·81	0·95	1·19	
,,	1540				1·40	1·61	0·81	0·95	1·19	
14.1.46	0815				1·40	1·61	0·81	0·95	1·19	
,,	1415				1·40	1·61	0·81	0·95	1·19	
,,	1415–1540		66·56	97·19						M.S. sheets
,,	1540				1·39	1·60	0·80	0·93	1·18	
15.1.46	0830				1·37	1·59	0·79	0·92	1·17	
,,	0830–0940		46·25	50·94						M.S. sheets
,,	0940				1·35	1·55	0·74	0·89	1·13	
,,	1605				1·35	1·54	0·74	0·89	1·13	
16.1.46	0800				1·35	1·53	0·73	0·88	1·12	
,,	0800–1000		50·94	0						Rails and M.S. sheets
,,	1000				1·27	1·50	0·67	0·79	1·06	
17.1.46	1450				1·23	1·47	0·65	0·75	1·03	

Estimated limits of accuracy = ± 0·02 inch

TABLE 4. *(See p. 71)*

Time: minutes	Gauge reading	Load on jack: tons	Uplift: tons	Rise: inch	Time: minutes	Gauge reading	Load on jack: tons	Uplift: tons	Rise: inch
0	0	0	0	0·00	46	1,320	24·3	48·6	0·88
1	60	1·1	2·2	0·00	47	1,330	24·5	49·0	0·91
2	70	1·3	2·6	0·00	48	1,330	24·5	49·0	0·93
3	80	1·5	3·0	0·01	49	1,330	24·5	49·0	0·98
4	110	2·0	4·0	0·01	50	1,350	24·9	49·8	1·01
5	120	2·2	4·4	0·01	51	1,360	25·0	50·0	1·05
6	140	2·6	5·2	0·01	52	1,360	25·0	50·0	1·09
7	170	3·1	6·2	0·02	53	1,370	25·2	50·4	1·14
8	190	3·5	7·0	0·02	54	1,370	25·2	50·4	1·18
9	230	4·2	8·4	0·02	55	1,370	25·2	50·4	1·21
10	260	4·8	9·6	0·03	56	1,380	25·4	50·8	1·25
11	310	5·7	11·4	0·03	57	1,380	25·4	50·8	1·28
12	360	6·6	13·2	0·03	58	1,380	25·4	50·8	1·32
13	410	7·6	15·2	0·04	59	1,380	25·4	50·8	1·37
14	460	8·5	17·0	0·04	60	1,300	24·0	48·0	1·38
15	510	9·4	18·8	0·05	61	1,280	23·6	47·2	1·37
16	550	10·1	20·2	0·07	62	1,140	21·0	42·0	1·36
17	610	11·2	22·4	0·08	63	1,100	20·3	40·6	1·36
18	660	12·2	24·4	0·09	64	1,070	19·7	39·4	1·36
19	710	13·1	26·2	0·10	65	1,030	19·0	38·0	1·36
20	760	14·0	28·0	0·12	66	1,280	23·6	47·2	1·38
21	810	14·9	29·8	0·14	67	1,330	24·5	49·0	1·40
22	860	15·8	31·6	0·16	68	1,320	24·3	48·6	1·40
23	910	16·8	33·6	0·19	69	1,330	24·5	49·0	1·42
24	960	17·7	35·4	0·21	70	1,310	24·1	48·2	1·42
25	1,010	18·6	37·2	0·22	71	1,360	25·0	50·0	1·46
26	1,060	19·5	39·0	0·23	72	1,360	25·0	50·0	1·50
27	1,110	20·4	40·8	0·24	73	1,150	21·2	42·4	1·50
28	1,150	21·2	42·4	0·25	74	1,080	19·9	39·8	1·49
29	1,170	21·6	43·2	0·27	75	1,050	19·4	38·8	1·49
30	1,230	22·7	45·4	0·29	76	1,040	19·2	38·4	1·49
31	1,240	22·8	45·6	0·32	77	1,040	19·2	38·4	1·48
32	1,240	22·8	45·6	0·34	78	1,000	18·4	36·8	1·48
33	1,250	23·0	46·0	0·40	79	1,000	18·4	36·8	1·35
34	1,260	23·2	46·4	0·44	80	350	6·4	12·8	1·29
35	1,260	23·2	46·4	0·48	80·5	120	2·2	4·4	1·25
36	1,270	23·4	46·8	0·52	81	40	0·7	1·4	1·25
37	1,280	23·6	47·2	0·55	81·25	0	0	0	1·24
38	1,280	23·6	47·2	0·60	81·5	0	0	0	1·23
39	1,300	24·0	48·0	0·63	81·75	0	0	0	
40	1,300	24·0	48·0	0·66	82	0	0	0	1·22
41	1,300	24·0	48·0	0·70	82·25	0	0	0	1·22
42	1,310	24·1	48·2	0·74	82·5	0	0	0	1·22
43	1,310	24·1	48·2	0·77	82·75	0	0	0	1·22
44	1,320	24·3	48·6	0·80	83	0	0	0	1·22
45	1,320	24·3	48·6	0·83	84	0	0	0	1·22
					1,415	0	0	0	1·22

TABLE 5. (*See p.* 71)

Date	Time	Load on: tons	Load off: tons	Total load: tons	Settlement: inch	Date	Time	Load on: tons	Load off: tons	Total load: tons	Settlement: inches
3.3.46	1115–1200	13·69		13·69						51·26	
”	1200				0·03	8.3.46	1230				2·00
”	1420				0·06	”	1230–1250		7·55	43·71	
”	1535				0·08	”	1255				2·23
”	1620				0·08	”	1330				2·23
4.3.46	0745				0·11	”	1400				2·23
”	1020				0·12	9.3.46	0810				2·25
”	1025–1045	7·57		21·26		”	1625				2·27
”	1045				0·16	”	1630–1645		7·34	36·37	
”	1225				0·18	”	1645				2·27
”	1400				0·19	10.3.46	1100				2·27
”	1550				0·19	”	1550				2·27
5.3.46	0750				0·22	11.3.46	0900				2·27
”	0940				0·22	”	1000				2·27
”	0940–1010	7·63		28·89		”	1000–1020		15·11	21·26	
”	1010				0·25	”	1020				2·25
”	1220				0·29	”	1345				2·25
”	1510				0·30	”	1540				2·25
”	1605				0·30	12.3.46	0810				2·25
6.3.46	0750				0·35	”	0900				2·25
”	0900				0·36	”	0900–0910		7·57	13·69	
”	0905–0925	7·48		36·37		”	0910				2·23
”	0925				0·39	”	1230				2·23
”	0945				0·40	13.3.46	0810				2·23
”	1225				0·45	”	0810–0830		13·69	0	
”	1440				0·45	”	0830				2·20
”	1550				0·46	14.3.46	0920				2·19
7.3.46	0805				0·51	”	1040				2·19
”	1010–1035	7·34		43·71		”	1335				2·19
”	1035				0·54	15.3.46	0815				2·16
”	1045				0·56	16.3.46	1530				2·16
”	1120				0·60	17.3.46	1300				2·15
”	1335				0·65	18.3.46	1010				2·15
8.3.46	0830				0·75	19.3.46	1620				2·15
”	1015				0·75	20.3.46	0805				2·15
”	1015–1055	7·55		51·26							
”	1055				0·81						
”	1100				0·82						
”	1220				1·92						

Settlement: 2·15 inches. Recovery: 0·12 inch.
Limits of accuracy: ± 0·02 inch.

Paper No. 5881

"Strengthening of Steel Structures under Load"

by

Terence Patrick O'Sullivan, Ph.D., B.Sc.(Eng.), M.I.C.E.

(Ordered by the Council to be published with written discussion) †

SYNOPSIS

The problem of providing an economical design for a large steel structure often causes anxiety to the engineer responsible for that design. He may wish to make adequate provision for possible increases in loading which may arise in the future. Such provision can add heavily to the prime capital cost and may subsequently be found unnecessary.

This Paper describes a new method of approach demonstrated by review of theory, full-scale tests, and practical application, by which existing structures can, with proper safety, be enabled to carry loads over and above that for which they were originally designed. By the application of this method it was possible to increase successfully the load-carrying capacity of a 331-foot-span arch to the Brabazon Assembly Hall at Bristol. It shows very great savings in time and cost over currently accepted methods.

INTRODUCTION

In providing a steel framework for the purpose of supporting structures of magnitude such as bridges and large works of an industrial nature, the engineer is often confronted with the task of choosing between two courses of action.

On the one hand it may be considered politic to make provision for future development or change of use, entailing allowance for loading over and above that specified at the time the work is begun. By so doing, however, heavy expenditure may be incurred which may never be justified. On the other hand, if provision for additional loading is not made, but is subsequently required, the engineer may, at a later date, be confronted with a technical problem of some considerable difficulty. Whichever course be adopted he is open to criticism, either for being responsible for what may be considered an extravagant design, or alternatively for showing lack of foresight.

However, if a structure, as designed and constructed, is later found liable to be subjected to excessive loading, it is the Author's opinion that

† Correspondence on this Paper should be received at the Institution by the 1st May, 1953, and will be published in Part I of the Proceedings. Contributions should be limited to about 1,200 words.—Sec. I.C.E.

the problem of providing for this excess loading is not so formidable as it appears at first sight.

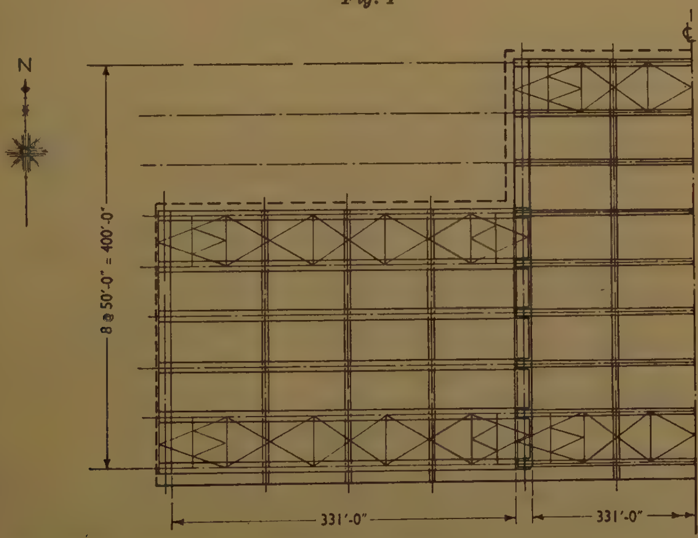
The new conditions that arose during the construction of the Brabazon Aircraft Assembly Hall at Bristol and methods by which this problem was overcome constitute the basis of this Paper.

THE BRABAZON AIRCRAFT ASSEMBLY HALL, BRISTOL

Brief Description

Full descriptions of the general work involved in the provision of the Brabazon Aircraft Assembly Hall are contained in two Papers by Mr Brian Colquhoun.[1, 2] However, a brief description is incorporated here to render this Paper self-contained.

Fig. 1



HALF-PLAN OF BRABAZON ASSEMBLY HALL

Fig. 1 indicates the lay-out. The interior consists of three bays, each of 331 feet clear span, the centre bay having a depth of 400 feet, and each of the side bays a depth of 250 feet. The roof consists of rubberized-felt carried on pressed-steel sheeting, whilst the walls are either of asbestos sheeting or glass.

[1] C. B. H. Colquhoun, "The Brabazon Assembly Hall at Filton." J. Instn Civ Engrs, vol. 32, p. 4 (March 1949).

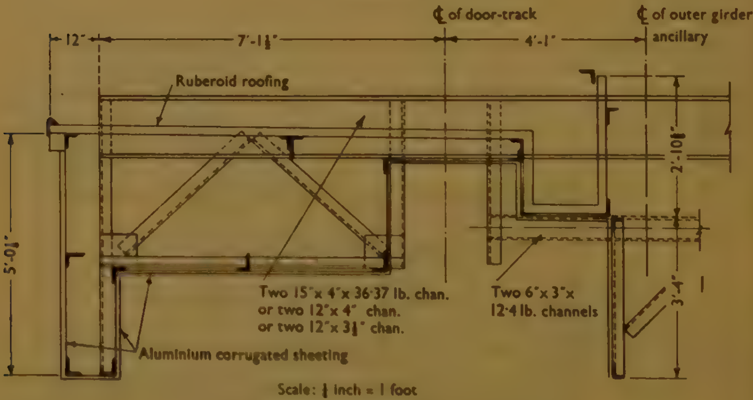
[2] B. H. Colquhoun, "Structural Aspects of the Brabazon Assembly Hall" *Structural Engineer*, vol. 27, p. 252 (June 1949).

The wall and roof cladding are carried by means of a system of cambered arch frames tied at haunch level. These frames are of lattice construction arranged in box formation, and are supported on hinge pedestals at the base. These main frames are placed at 50-foot centres as shown.

The north side is generally glazed, whilst folding doors give access over the whole length of the south side. The east and west sides are covered for the greater part with asbestos sheeting, but a limited amount of glazing is incorporated.

In the original scheme the south side of the Assembly Hall was to be provided with a small canopy only, over the doors. Following the completion of erection of the main arches at the south side, however, it was required that a more extensive canopy should be included, a section of which is shown in *Fig. 2.*

Fig. 2



SECTION THROUGH CANOPY

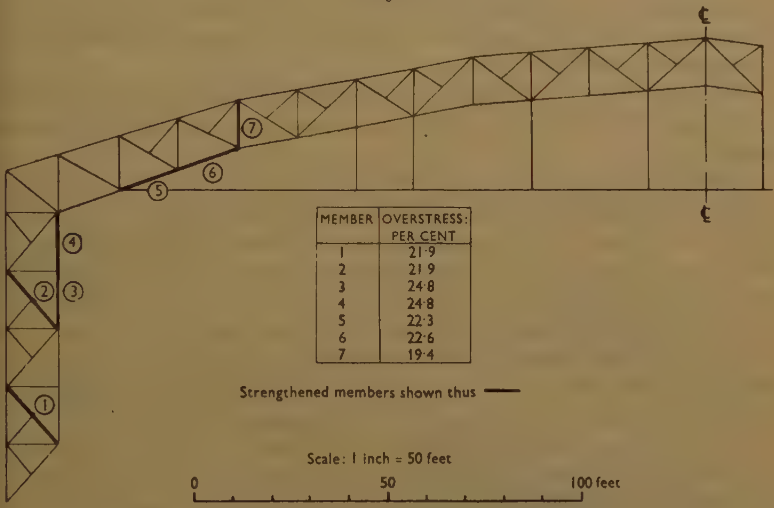
The steel channels which carry the canopy are cantilevered out from a box girder which was installed for the purpose. This box girder is carried by other box girders, running in a longitudinal direction, which support the rails for the travelling crane bridges, the box girders being carried in turn by suspenders from the main arch frames.

Investigations showed that the increase in dimensions of the canopy would lead to overstressing of the material in certain members. The members affected are shown in *Fig. 3*, which includes a Table showing the extent of the overstress under the worst possible conditions of loading.

It should be noted that all permissible stresses were in accordance with the current British Standard No. 449, with the exception of a specified overload for snow. Owing to the large expanse of roof it was found that the reduction in stress due to the suction effect from a lateral wind was greater than the increase due to racking action. Hence the question

of permissible increase in stress under the action of wind loads did not arise. The consulting engineers then considered that they were justified in allowing a 15 per cent increase in permissible stress caused by snow

Fig. 3



MEMBER	OVERSTRESS: PER CENT
1	21·9
2	21·9
3	24·8
4	24·8
5	22·3
6	22·6
7	19·4

KEY ELEVATION OF HALF MAIN RIB

loading, in view of the fact that the effect of wind was to decrease rather than to increase the stresses.

PROPOSED SOLUTION

To meet the request for an increase in size of the canopy, it became necessary to determine precisely what steps should be taken to increase the strength of those members which would have been inadequate in the existing structure under full-load conditions.

When giving effect to a decision on policy in that matter, it was found that the stresses present in the members under review were about 60 per cent of the working stress, because the crane and snow loads were not being applied.

It would seem that, on the basis of the accepted concepts of the elastic theory, with maximum permissible working stress as a governing factor, any strengthening material applied to provide additional cross-sectional area could be worked to only 40 per cent of the permissible stress, otherwise the stress in the parent metal would exceed the permissible. To enable full value to be obtained from the additional material, release of stress in the parent metal prior to a strengthening would be called for.

The effect of carrying out either of these measures was then considered further.

The incorporation of material to be worked at a maximum stress of 40 per cent of the permissible, apart from being itself uneconomic called for scantlings of strengthening material large in comparison with the parent member. To achieve the most economic transference of stress it was necessary for the proportion of additional cross-sectional area to be kept as low as possible.

With regard to the alternative of causing temporary release of stress in the members, two methods were considered, namely, local and general release.

Local release would have involved the drawing together or jacking apart of the ends of individual members—a slow operation calling for special equipment. On the other hand, general release by means of jacking-up of the main ties to the roof girders at suspender points was ruled out immediately, since, apart from the cost of erecting trestles from the floor, partial dismantling of the box girders carrying the crane rails would have been necessitated. It should be borne in mind that the deflexion of the south arch at the centre, as a result of self-weight and permanent fixtures was of the order of 11 inches.

In view of these different conditions, the Author decided that it would be advisable to examine, in detail, an arrangement for strengthening, in which material was added while the structure was under load, but in which the area of this additional material was calculated on the assumption of there being no initial stress in the material of the parent member. This meant that the area of the additional material would be calculated on the assumption that its load-carrying capacity would be based upon the permissible working stress, and not the difference between this permissible stress and the initial stress in the parent member.

For example, *Fig. 4* (*a*) shows the general conditions of an unstrengthened tie subjected first to a working stress of T at a load of 10 tons, and finally to a yield stress of $2T$, in which case the load is 20 tons. The extension at working stress is x and that at yield stress $2x$. It is assumed in all cases that a straight-line stress/strain relationship applies up to yield point.

Fig. 4 (*b*) shows the same tie strengthened while unstressed by the addition of material of cross-sectional area equal to that of the parent member. The load at working stress is now 20 tons, and at yield stress 40 tons, and the respective extensions are again x and $2x$.

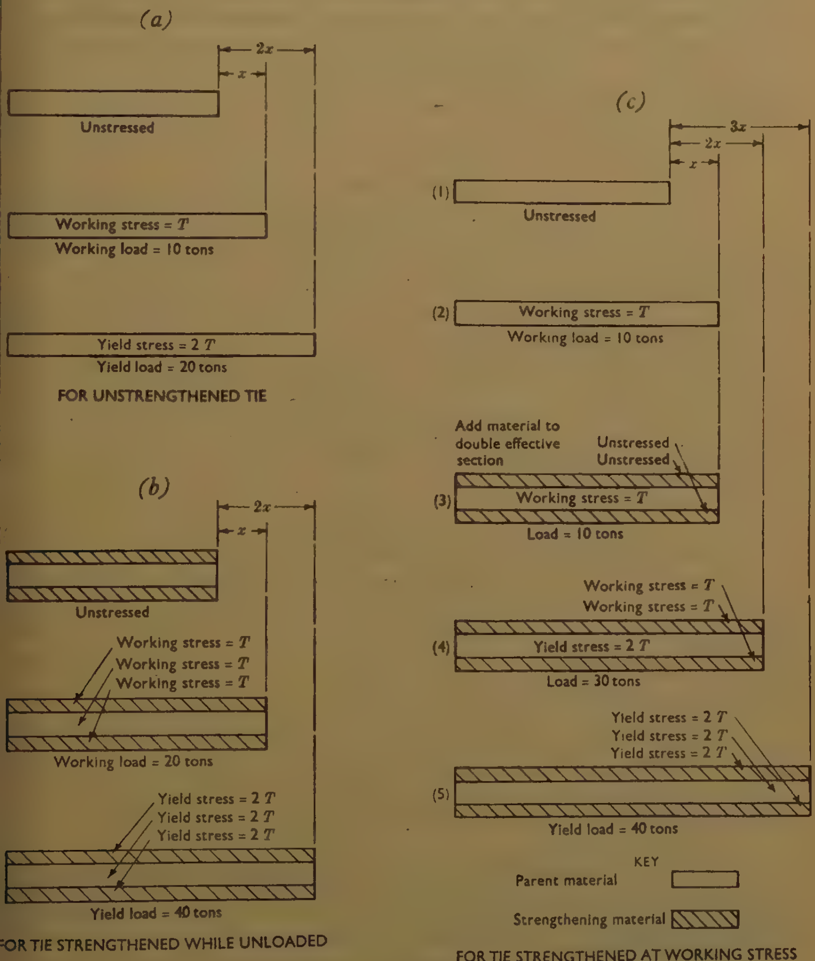
Now consider the case of the tie strengthened under load as indicated in *Fig. 4* (*c*). The unstressed tie is shown at (1). Under a working load of 10 tons producing a working stress of T the tie extends a distance x as shown at (2). The strengthening material is then added to double the cross-sectional area, and the circumstances are as shown at (3).

A further 20 tons is now added, bringing the load to 30 tons, in which

case the parent material reaches yield stress $2T$, while the strengthening material reaches working stress T, and the extension becomes equal to $2x$ as shown at (4).

Finally, a further 10 tons is added, bringing the total load carried to

Figs 4



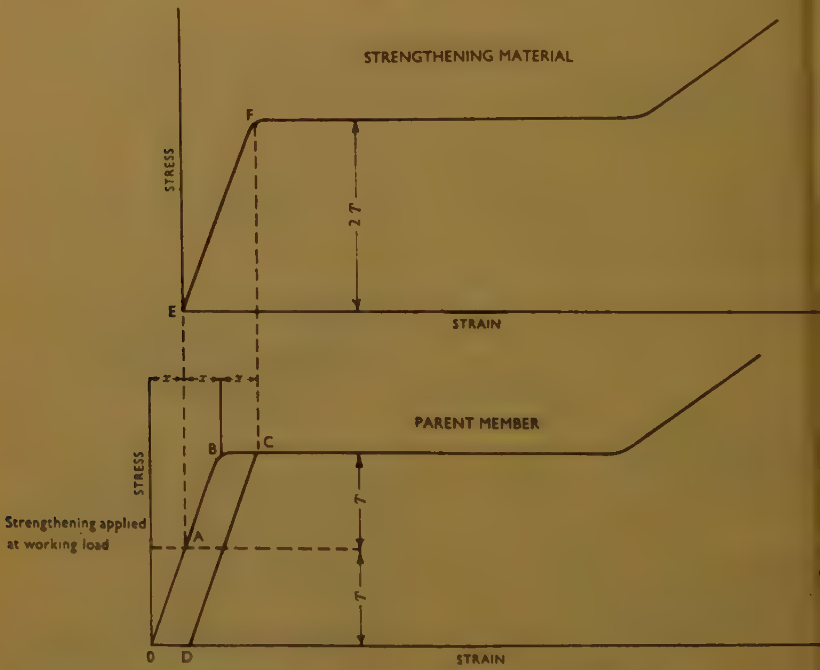
EXTENSION DIAGRAMS

40 tons, which brings the stress in the strengthening material to yield stress $2T$, and an extension of the composite member of $3x$. Those conditions represent the effective yield point of the composite member. It will be noted that between conditions (4) and (5) no increase in stress takes place

in the parent metal, this remaining constant at the yield stress, $2T$. Consequently, when the load on the composite member is increased after the stress in the parent metal has reached yield, such increase in load is accommodated entirely by the additional material.

The case of the tie strengthened while under load may be further considered from inspection of the stress/strain diagram in *Fig. 5*. Position A on the stress/strain line is reached when the application of load results in a working stress of T and an extension of x in the parent member.

Fig. 5



STRESS CYCLE FOR MEMBER STRENGTHENED UNDER LOAD

At this stage additional material is applied and the load increased until the stress in the material is equal to $2T$ or the yield stress and its extension equal to $2x$. At the same time the parent metal passes through yield point B with extension x, and on to the point C with a further extension of x, making a total extension in the parent metal equal to $3x$.

Upon release of the load the strengthening material returns to point E with full release of strain, while the parent metal returns from C to D with a residual strain of x. It is a point of interest that the stress in both the parent and additional materials will be the same as the load is reduced and each will reach zero stress at the same time.

Also if, after complete release of load, the load was re-applied, then the stress would be equal across the entire composite section.

From consideration of the foregoing it was the opinion of the Author that effective yield of the composite member could not take place until the strengthening material itself had yielded. That appeared to obviate the necessity for release of load in order to obtain the full value of the strengthening material.

However, prior to the acceptance of this hypothesis as a basis under which the south arch should be made capable of carrying increased loads, it was decided that a number of full-scale tests should be made. These are described below.

Experimental Evidence

Testing Machine.—Dorman Long & Co. Ltd, sub-contractors to Redpath Brown & Co. Ltd, for the erection of the steel framework of the Assembly Hall, have in their possession at their works at Middlesbrough a testing machine capable of applying 1,250 tons load to members of length up to 50 feet. This machine was made available by them for the series of tests arranged to determine the effect of strengthening prior to and after the application of load.

Test of Tension Units.—The upper part of *Figs 6* shows the details of a strengthened test unit as set up ready for testing. It will be seen that

TABLE 1.—TENSILE-TEST NOTES

Specimen	Strengthening	Yield	Failure	Type of failure
D1 D2	Nil Nil	90 tons 90 tons	177 tons 180·5 tons	Fracture at centre Fracture at centre
E1 E2	Strengthened while unloaded	180 tons 185 tons	286 tons 292 tons	Fracture through first holes in end splice
F1	Strengthened under normal working load	180 tons	291 tons	Fracture through welds at end splice
F2	Ditto. Extra ¾″-dia. hole drilled at centre.	180 tons	290 tons	Fracture at centre.
F3	Ditto.	180 tons	285 tons	Fracture at centre. Strengthening plates broke first

	Areas
TEST SPECIMENS: 9″ × ¾″ × 10′–0″ plate . .	6·75 sq. in.
STRENGTHENING: Two plates each 9″ × ⅜″ × 10′–0″	6·75 sq. in.

each unit has a total length of 16 feet 0¼ inch and consists of a 9-inch-by-¾-inch plate strengthened by 9-inch-by-⅜-inch plates. Turned and fitted bolts, ⅞ inch diameter, were used at the splices, whilst for tacking purposes ¾-inch-diameter black bolts were used.

The tension-test programme consisted of seven tests, all as indicated in *Figs 7*.

Fig. 8 is a view of strengthened tie-bar after failure.

Test of Compression Units.—The lower part of *Figs 6* shows the details of a strengthened compression unit as set up ready for testing. In this case, the overall length of the unit is 15 feet and it consists of two channels 12 inches by 4 inches by 31·33 lb. arranged back to back but separated by a 9-inch-by-¾-inch plate. The strengthening material consists of four 3-inch-by-⅝-inch plates, each attached to the inside of the flanges of the channels. As in the case of the tension units the end bolts are ⅞ inch diameter, turned and fitted, whilst the intermediate bolts are ¾-inch-diameter black bolts.

TABLE 2.—COMPRESSION-TEST NOTES

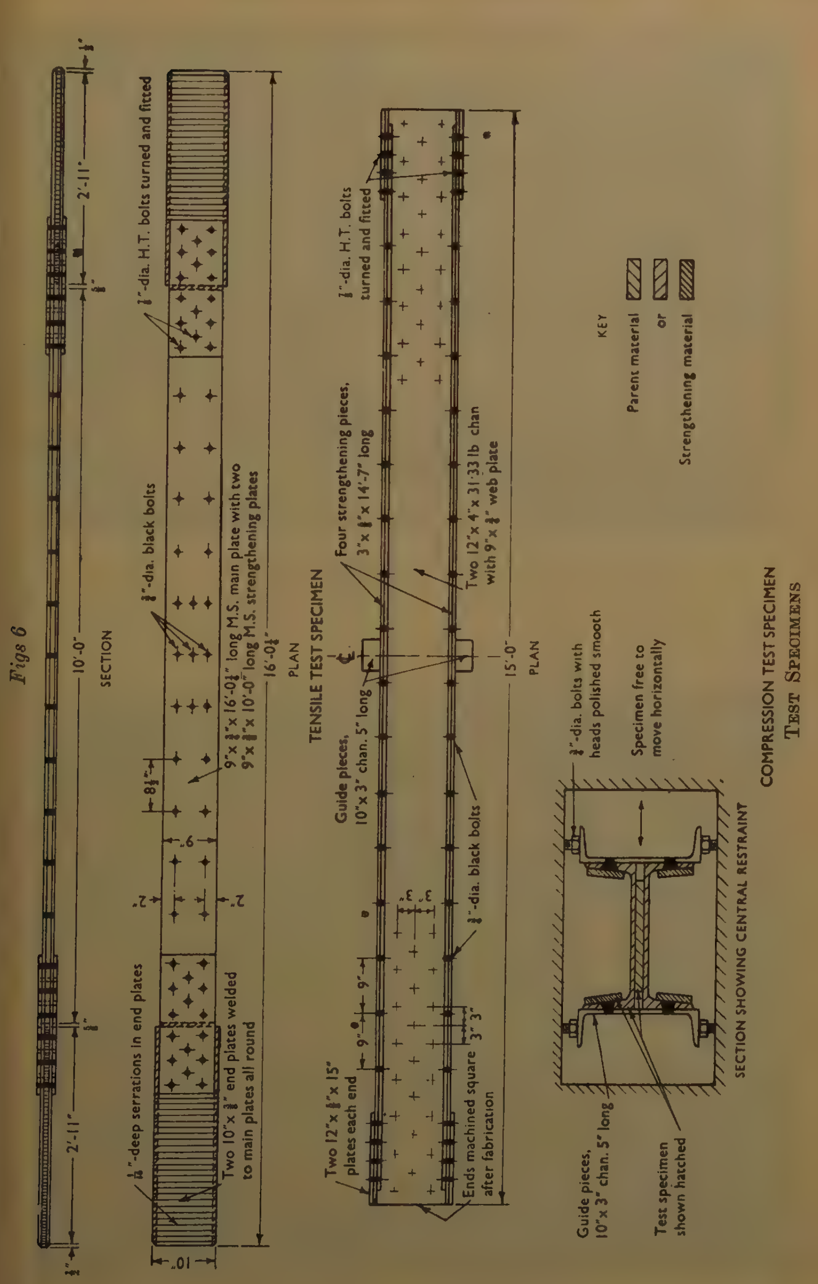
Specimen	Strengthening	Yield	Failure
A	Nil	320 tons	345 tons
B1	Strengthened while unloaded	450 tons	465 tons
B2		440 tons	468 tons
C1	Strength under normal working load	430 tons	430 tons
C2		420 tons	460 tons

		Areas
NOTE:	Bolt clearances in Specimen C1 were excessive.	
TEST SPECIMENS:	Two channels 12″ × 4″ × 31·33 lb. One web plate 9″ × ¾″ (all 15′-0″ long)	18·42 sq. in. 6·75 ,, = 25·17 ,,
STRENGTHENING:	Four plates each 3″ × ⅝″ bolted to inside of flanges	7·50 ,, = 30% increase

The compression-test programme consisted of five tests, all as indicated in *Figs 9*.

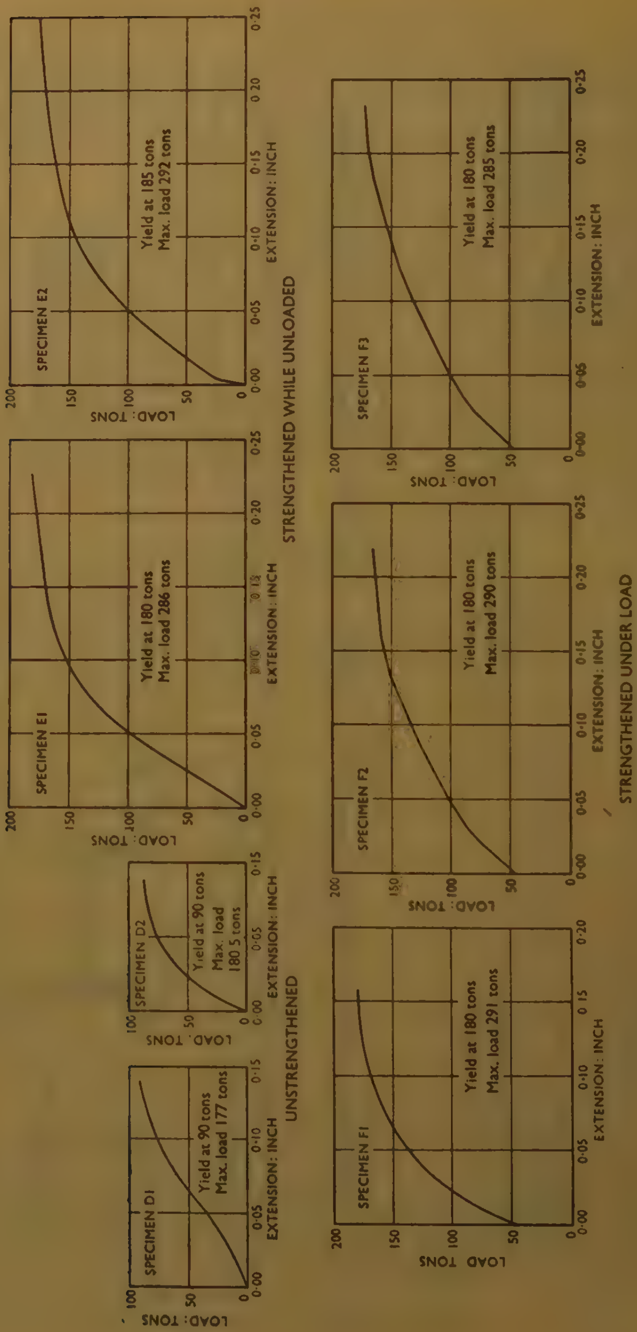
Fig. 10 shows unstrengthened strut "A" immediately after failure. It also illustrates the method used for providing lateral restraint at the mid-point of the strut. Thus the actual conditions applying to the structure itself were simulated.

Fig. 11 shows a strengthened strut after failure. It will be observed



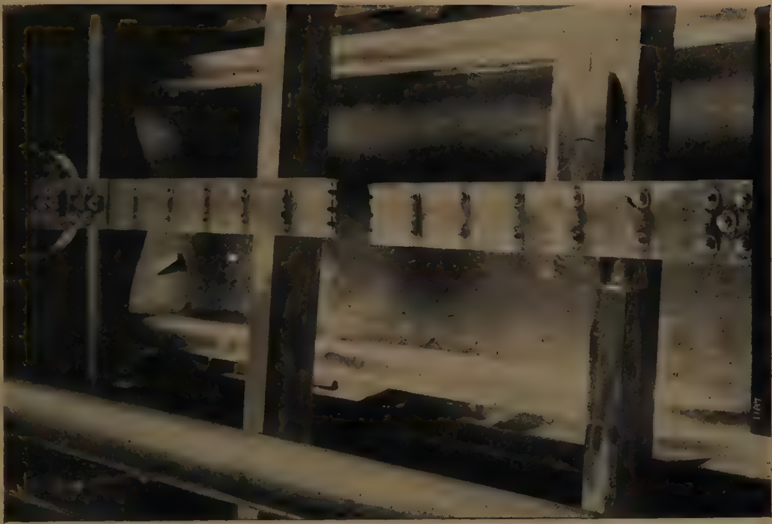
TEST SPECIMENS

Figs 7



TENSILE-TEST DIAGRAMS

Fig. 8



STRENGTHENED TIE-BAR AFTER FAILURE

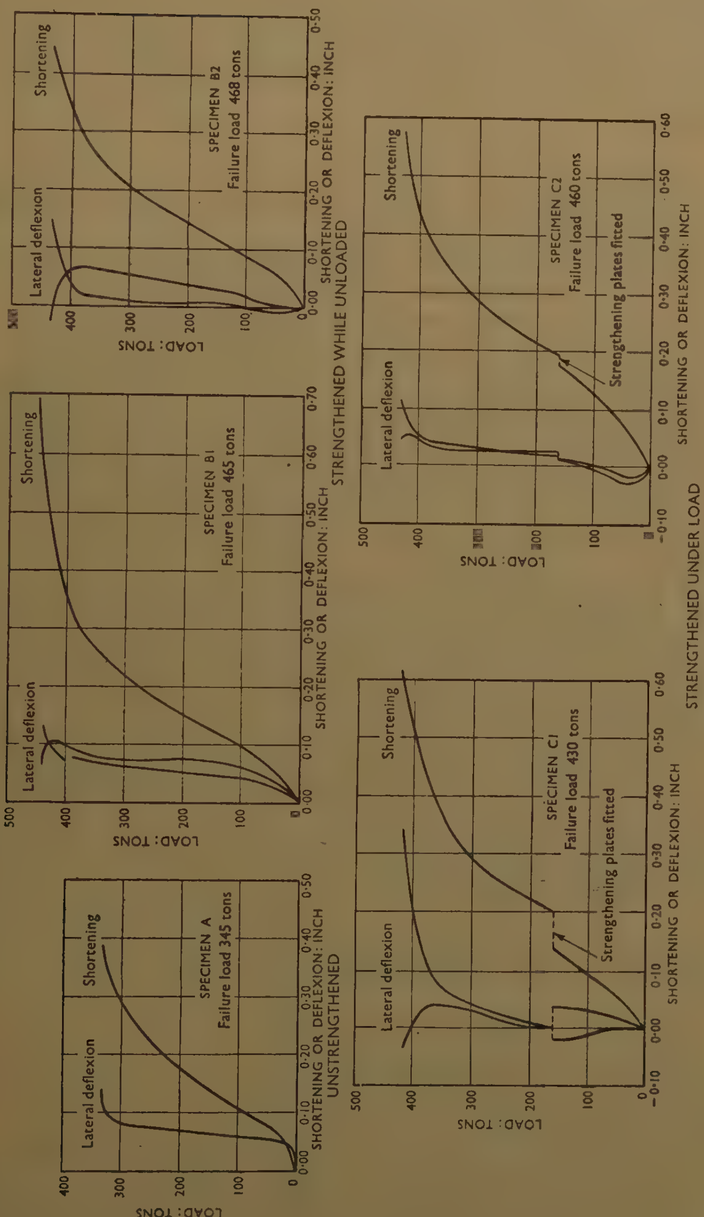
Fig. 10

UNSTRENGTHENED STRUT "A" IMMEDIATELY AFTER FAILURE

Fig. 11

STRENGTHENED STRUT AFTER FAILURE

Figs 9



COMPRESSION-TEST DIAGRAMS

that failure of the member has been accompanied by local buckling of the flats between the tacking bolts. The slenderness ratio of the whole member and that of the additional flats taken locally between the tacking bolts is approximately equal. The question of local weakness of additional material must always be carefully investigated during any strengthening operation.

Review of Results

In the first place the results of tests on tension units as scheduled in *Figs 7* are considered.

Specimens D1 and D2 were unstrengthened, and the average yield and maximum loads were 90 and 180 tons respectively.

Specimens E1 and E2 were strengthened while unloaded and the average yield and maximum loads were 182 tons and 289 tons.

Specimens F1, F2, and F3 were strengthened under load, and the average yield load was 180 tons and the average maximum load 289 tons.

It is therefore apparent that, in respect of both yield and failure load, test series E and F gave substantially the same results. This leads to the conclusion that members strengthened while at working load exhibit the same yield and failure strength as those strengthened while unloaded.

It is worthy of note that in strengthening, although the gross sectional area has been doubled (that is, the addition of two 9-inch-by-⅜-inch flats to the original 9-inch-by-¾-inch flat) the net sectional area is considerably less than this as a result of the loss of material caused by bolt holes. This loss is not shown by the yield of the strengthened unit, which is double that of the parent unit—180 tons in lieu of 90 tons. The reason for this is that the intensity of stress adjacent to the holes is treble the normal stress intensity. It will be seen, however, that at failure the ultimate strength of the unit after strengthening is governed by the reduction of effective area caused by bolt holes (289 tons compared with 180 tons).

Next will be considered the results of the compression tests as scheduled in *Figs 9*. The yield strengths in compression are somewhat indefinite, and the Author prefers to draw conclusions from the ultimate strengths.

Specimen "A", the unstrengthened strut, had a failure load of 345 tons.

The average failure loads of specimens B1 and B2, which were strengthened while unloaded, was 466 tons.

The failure load of specimens C1 and C2, which were strengthened under load, were 430 tons and 460 tons respectively.

Here it will be observed that groups B and C, that is, those strengthened while unloaded and strengthened at working load respectively, are substantially the same except in the case of unit C1, for which the ultimate value is low. Careful measurements of clearances between fitted bolts and bolt holes were made, and it was found that as a result of the use

of a different drill for this unit the average clearance was 0·020 inch in the case of C1, compared with only 0·008 inch in the case of the remainder.

In view of this difference in bolt clearance it was considered justifiable to accept the findings of specimen C2 rather than those of C1, for purposes of comparison.

The increase in cross-sectional area of each unit is 30 per cent after strengthening, whereas the increase in ultimate strength is 34 per cent, neglecting unit C1. In view of the increase of the moment of inertia as a result of adding material to the cross-section, and the resulting increase in stiffness, some excess in percentage of increase of ultimate loads compared with increase in cross-sectional area is to be expected.

Findings and their Application

The results of the tests indicated above confirm that the load at effective yield in the case of either tension or compression units is substantially the same whether the member is strengthened when unstressed or at working stress, thus the carrying capacity of a member strengthened under load is unaffected by the conditions under which strengthening is carried out.

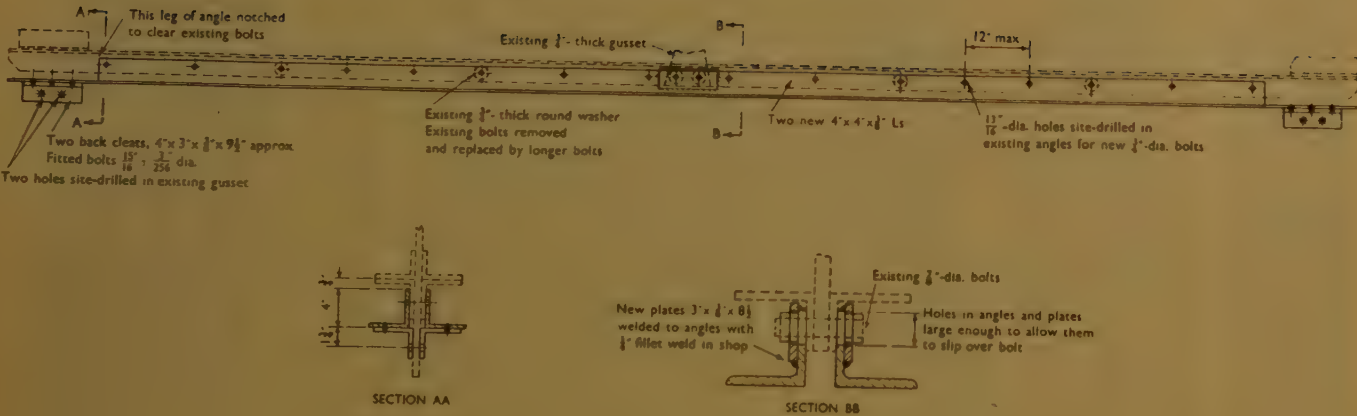
It will be seen, however, from an examination of *Figs 4* and *5*, that under such conditions the extension at yield is 50 per cent more than that of a member strengthened while unstressed. However, in this instance only a small proportion of the members is affected, so that increase in deflexion even at yield would have a negligible effect on the total deflexion of a frame. It is considered reasonable to assume that this would be the normal condition in the event of strengthening having to be carried out on a frame of many members, that is to say, that only a certain number of the members would be in need of strengthening.

It should be borne in mind that the extension of a member at full yield is about twenty times the total elastic extension. It is therefore this full yield stress and extension that must be guarded against, since distortions arising from it may be of such a nature as to cause, in effect, the failure of the structure.

The steps resorted to in practice to augment the strength of certain members to allow the arch to take the additional canopy load are shown in *Figs 12*, *13*, and *14*. The numbers of members to which reference is made are as shown in *Fig. 3*.

Figs 12 show the arrangement in respect of members Nos (1) and (2). The parent members consist of back-to-back angles. The strengthening material also consists of two angles. It was necessary to drill large holes in the vertical legs of these angles to accommodate the bolt heads and nuts of the existing central connexion. (Section B B). At the ends the vertical legs are notched clear of the connexion, and the outstanding legs only are carried through and cleated to the existing gusset plate, with turned and fitted bolts (Section A A).

Figs 12

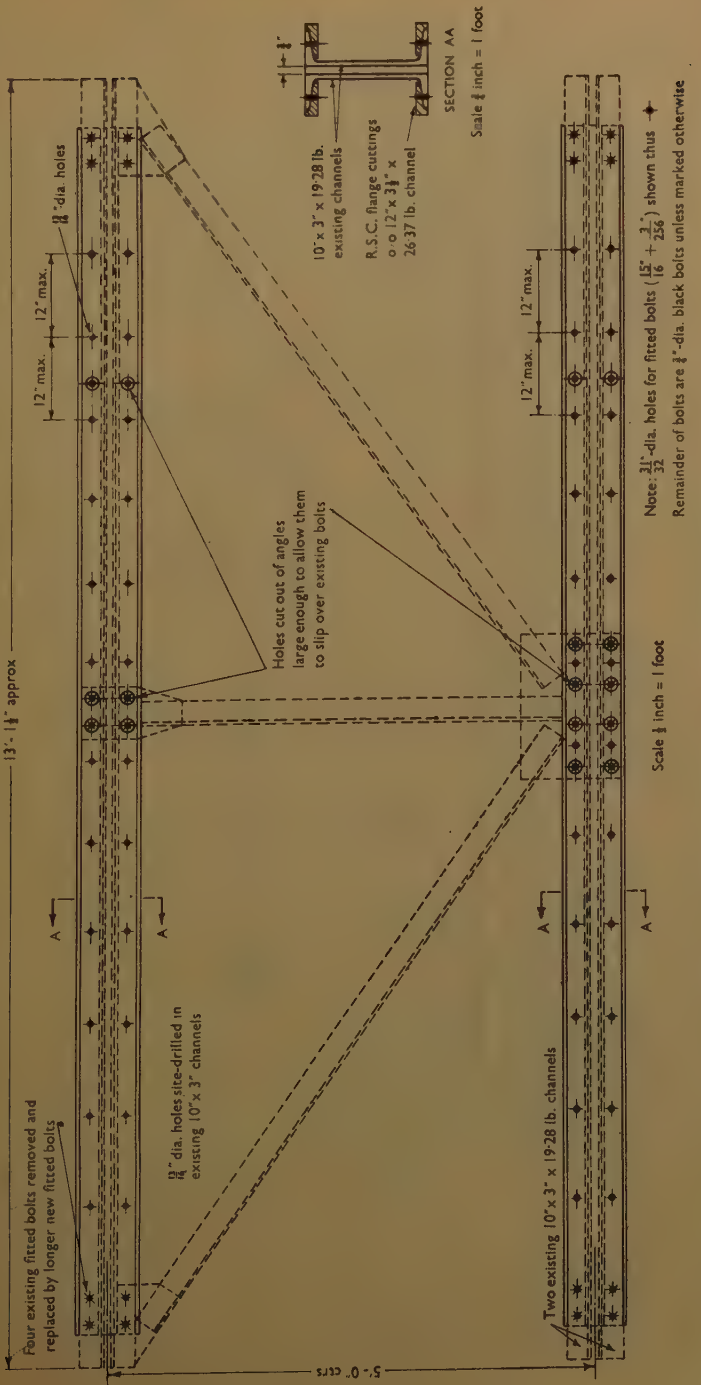


Note: 31/32"-dia. holes for fitted bolts (15/16" + 3/256") shown thus

Remainder of bolts are ¾"-dia. black bolts unless marked otherwise

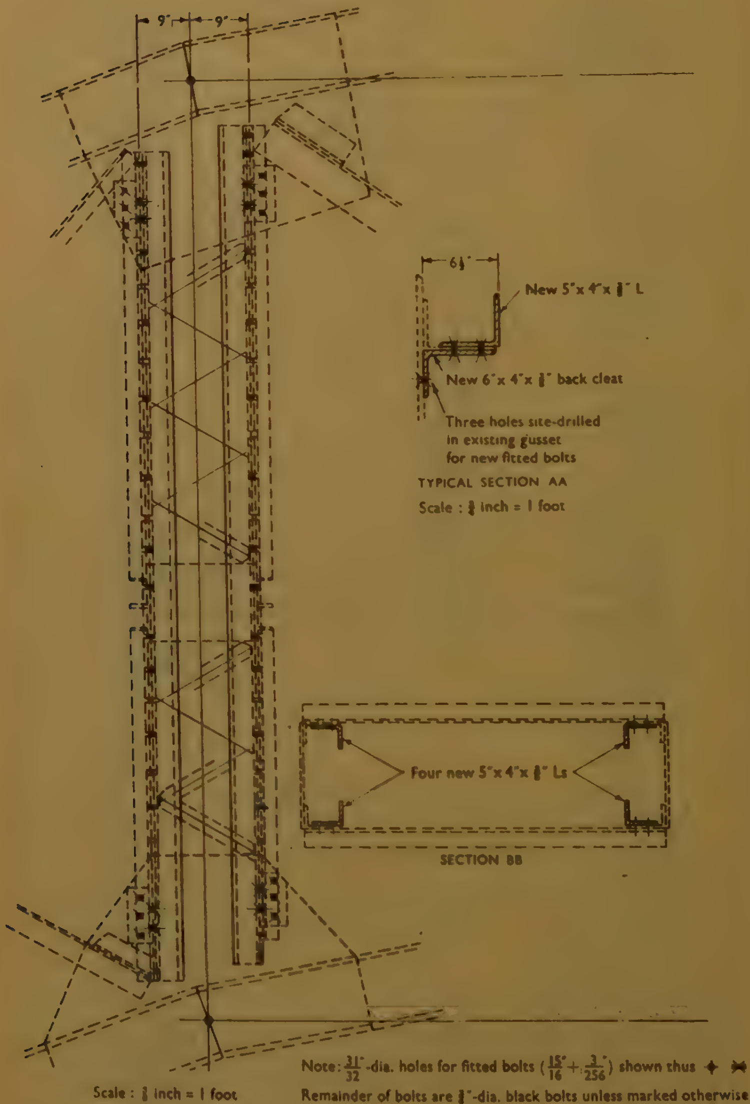
DETAILS OF STRENGTHENING TENSION MEMBERS 1 AND 2

Figs 13



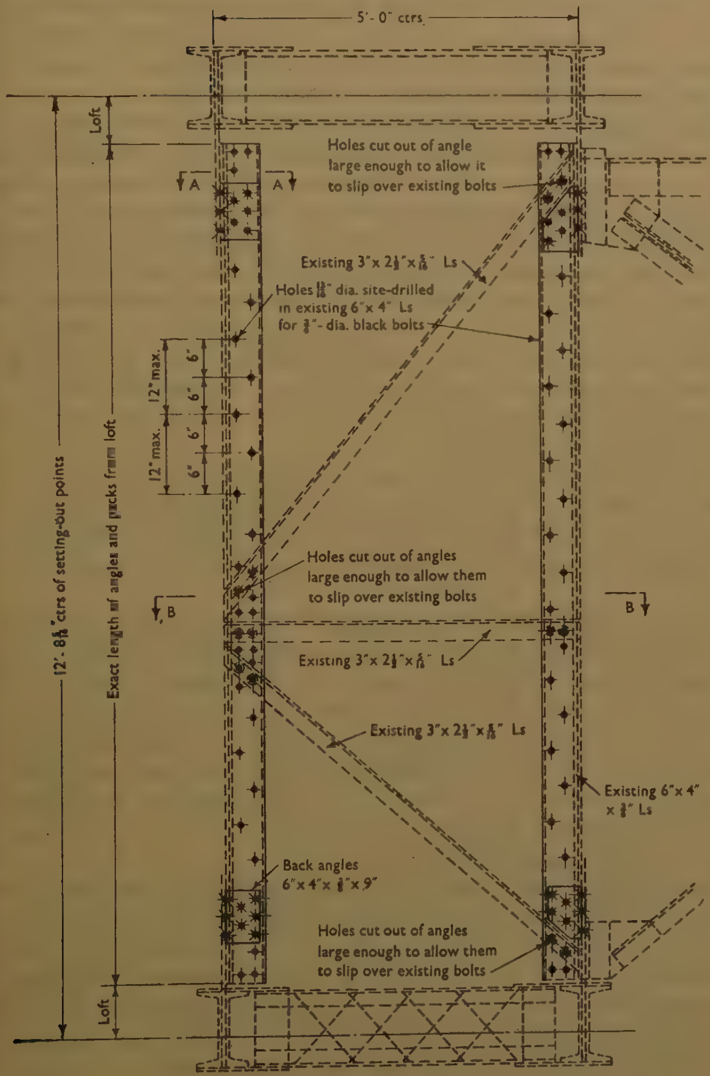
Details of Strengthening of Compression Members 3 to 6

Fig. 14 (a)



DETAIL OF STRENGTHENING OF

Fig. 14 (*b*)



Scale : ⅜ inch = 1 foot

COMPRESSION MEMBER 7

The strength of the existing end connexions must be investigated if additional load is being applied to the members. Generally end connexions have a greater factor of safety than the members themselves, and may be adequate to accommodate additional loads without overstressing. If, however, these end connexions are found on investigation to be inadequate, then additional drilling and bolting will be required.

Figs 13 show the arrangement for increasing the carrying capacity of the double-channel sections (3) to (6) inclusive. Here, in lieu of flats as used in the tests, channel-flange cuttings have been employed in order to obviate the necessity for bevelled washers. A general detail is shown in Section A A. Again it has been necessary to drill holes in the channel cuttings large enough to allow them to slip over the existing bolt heads and nuts at connexion positions. In determining the centres of the tacking bolts, the local slenderness ratio of the channel cutting must be taken into account. The turned and fitted bolts at the ends of the member were replaced by larger bolts, but not increased in number, thus indicating that the existing end connexion was considered adequate to deal with the extra loading.

Finally, *Figs 14* show the strengthening arrangement in respect of lattice member (7). Here, four new angles have been provided on the inside as shown in Section B B, and the end connexions reinforced with additional cleats and bolts. Details of these cleats are shown in Section A A.

It will be noted that in this example of the Bristol Hangar all the work is of riveted and bolted construction involving cleats, gussets, and holes. Material has been added by bolting it to the parent members. If it were possible to weld the additional material to the existing in position at the site, the process of strengthening would be much simpler. This would be especially so if the existing structure itself were welded. The cleaner lines, which are a feature of welded work, and the absence of awkward gussets and plates would make the members much more conducive to effective strengthening.

However, the strengthening of the south arch of the Brabazon Aircraft Assembly Hall was carried out in accordance with the principles explained, and as detailed in the Figures shown. The outcome was entirely satisfactory, and the Author would have no hesitation in adopting the same technique for the design and detailing of strengthening material on other large structures where the load to be applied was subsequently found to be greater than that allowed for in the design.

Acknowledgements

The Author wishes to thank the Bristol Aeroplane Co. and Mr Eric Ross, F.R.I.B.A., Architect to the Company, for permission to publish references to the work carried out on the Brabazon Aircraft Assembly

Hall. He also wishes to thank Mr Brian Colquhoun, B.Sc.(Eng.), M.I.C.E., of Messrs Brian Colquhoun & Partners, the consulting engineers, for similarly granting his permission.

The Author desires to acknowledge the co-operation received from Mr J. F. Pain, M.C., B.Sc.(Eng.), M.I.C.E., of Messrs Dorman, Long & Co., Ltd, in granting the facilities for the full-scale tests at Middlesbrough; also to Mr J. O. Evans for his work in connexion with the actual tests. Considerable assistance was given by Mr R. Bolsover in the preparation of the text and drawings.

The Paper is accompanied by eleven photographs and eleven sheets of diagrams, from some of which the half-tone page plates and the Figures in the text have been prepared.

OBITUARY

THE RIGHT HON. LORD MACMILLAN, G.C.V.O., Q.C., who died at his home in Surrey on the 5th September, 1952, at the age of 79, was born at Glasgow on the 20th February, 1873, the only son of the Rev. Hugh Macmillan, D.D., LL.D.

He studied first at the University of Edinburgh, graduating in 1893 with first-class honours in Philosophy. He then went to the University of Glasgow, where he read Law, graduating in 1896—Chief Prizeman of his year.

He became an advocate in 1897, and whilst building up his practice he was an Examiner in Law for the University of Glasgow (1899–1904), and Editor of the *Juridical Review* (1900–07).

Specializing in Parliamentary work, he took silk in 1912, and had, by the time the First World War broke out in 1914, attained a high reputation for his legal ability.

The first of the many high offices of the Crown came to him in 1918, when he was appointed Assistant-Director of Intelligence at the Ministry of Information—he became Minister of the self-same Ministry many years after, in 1939.

In 1924, when the Labour Party was returned to power for the first time, Lord Macmillan was appointed Lord Advocate of Scotland, although he had no political affiliations ; it was at this time also that he was sworn in as a member of the Privy Council.

Not only will Lord Macmillan be remembered for his erudition as a legal luminary, but also for the great work he did for over twenty years as the Chairman of a large number of Parliamentary Commissions, the subjects of which were as varied as they were numerous.

The width and diversity of his interests and talents will be borne out by the many offices he held in connexion with the Arts. He was, for example, a Trustee of the British Museum, the National Library of Scotland, and the National Trust, and Chairman of the B.B.C.'s Advisory Council (1937–47), to name only a few.

One office which he held up to the time of his death afforded him particular pleasure, however, namely, the Chairman of the Pilgrim Trust.

Among the many honours conferred upon him, which included Honorary Doctorates of many Universities, was the award, in 1937, of the Grand Cross of the Royal Victorian Order.

Lord Macmillan was made an Honorary Member of the Institution in 1928 in recognition of his distinguished career at the Bar, and his great interest in the work of the Civil Engineer, the latter being made most

patent when he delivered one of a series of four Lectures to the Institution in 1946, under the general title "The Presentation of Engineering Evidence."*

In 1901, he married Elizabeth Katherine Grace, daughter of Dr W. J. Marshall of Greenock, who survives him.

SYDNEY BRYAN DONKIN, who died at Albury, Surrey on the 12th November, 1952, at the age of 81, was born on the 24th June, 1871.

The name Donkin first appeared on the Roll of the Institution in 1821, when a Bryan Donkin—a contemporary of Telford—was elected a member. Since that date the name has always appeared on the Roll, borne successively by father, son, grandson, great grandson, and great great grandson.

Mr Donkin was educated privately, and at University College, London. He obtained his practical training by becoming, in 1888, pupil with his father, Mr Bryan Donkin, and later he went to Switzerland where he spent 3 years with Messrs Sulzer Bros., of Winterthur.

Returning to England in 1893, he rejoined Messrs Bryan Donkin and Co., first as draughtsman, later becoming Assistant to the Manager.

In 1897 he left to become Assistant to the late Sir Alexander Kennedy, thus joining the firm with which he was to become associated for the remainder of his life.

From the outset of his career Mr Donkin specialized in the design and installation of electrical traction and generating equipment, and was responsible for electrification works in many parts of the world, including Egypt, Uganda, India, and Japan, where a hydro-electric scheme was constructed to his design. In Great Britain he was responsible for the electrification of suburban railways round London, and also a large number of generating stations throughout the country. He was an expert on heating problems, in connexion with which he read a Paper before the Institution in 1936—"Industrial, Agricultural, and Domestic Heating, with Electricity as a By-product." [1]

Mr Donkin was made a partner in his firm in 1908, and when Mr J. M. (later Sir John) Kennedy left the partnership to take up the appointment of deputy Chairman of the Electricity Commission in 1934, he became senior partner.

In addition to being Consulting Engineer to the Central Electricity Board of Northern Ireland in connexion with their grid schemes, a member of the Panel of advisers to the North of Scotland Hydro-Electric Board, and a member of the Hydro-Electric Power Commission in Egypt, Mr Donkin was a member of many important committees of the Department of Scientific and Industrial Research, the British Standards Institution, and the Home Office.

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* "The Giving of Evidence before a Parliamentary Committee, in the High Court, and before an Arbitrator."

[1] J. Instn Civ. Engrs, Vol. 1, p. 378 (Jan. 1936).

In the first World War he was a member of the Munitions Committee, and in addition held high rank in the Special Constabulary.

Elected an Associate Member of the Institution in 1898, Mr Donkin was transferred to the class of Member in 1912. He was a Member of Council from 1926, Vice-President in 1934, and became President of the Institution in 1937.

He was also a Member of the Institutions of Mechanical and Electrical Engineers.

He leaves a daughter, and three sons—two of whom are engineers.

HARRY CUNNINGHAM, who died on the 5th October, 1952, at the age of 75, was born at Glasgow on the 15th May, 1877.

He was educated at Spiers School, Beith, Scotland. In 1895 he became a pupil with Messrs Crouch and Hogg, of Glasgow, where he gained experience in the design and construction of bridges ; during this period he also studied at Glasgow Technical College.

On the completion of his pupilage in 1899, he joined the staff of the Chief Engineer of the Caledonian Railway Company, first as Assistant Resident Engineer, and latterly as Resident Engineer, on the Clyde Bridge Contract of the Glasgow Central Station Extension.

Whilst on the Clyde Bridge contract he attracted the notice of the late Sir William Arrol, who invited him to join his staff. This he did in 1906, thus beginning an association with this Company which lasted until Mr Cunningham's death.

For the first seven years of his career with the Company, he was Resident Engineer on many major works of bridge and docks construction, in particular the widening of Blackfriars Bridge, and the building of the Walney Bridge, Barrow-in-Furness.

However, in 1913 he was elected to the Board of the Company, and thereafter was concerned largely with the problems of management, and in particular those which the difficult years of the First World War presented. After the cessation of hostilities in 1918, he travelled extensively throughout the world in connexion with the many overseas contracts his firm had secured.

In 1935 he was appointed Chairman of the Company—a position he held up to the time of his death.

He also served as Chairman of a large number of trade associations, and will especially be remembered for his notable work during the Second World War, when, as Chairman of the British Constructional Steelwork Association, he was largely instrumental in obtaining the co-ordination of the resources of the structural steelwork industry.

Mr Cunningham was elected an Associate Member of the Institution in 1902, and was transferred to the class of Member in 1920.

He leaves a widow and a daughter.

GAVIN HEYNES JACK, who died on the 22nd September, 1952, at the age of 78, was born on the 21st January, 1874.

Educated at Warwick School, he became in 1889 pupil with the late Mr E. M. Richards, then Borough Engineer of Warwick.

On the completion of his pupilage, in 1893, he became Assistant Engineer to the Urban District Councils of Pontypridd and Caerphilly.

He left Wales in 1897 to become Deputy Engineer and later Engineer to Aston Manor, Birmingham.

In 1907 he was appointed County Surveyor and Architect of Herefordshire and remained as such for 26 years, until his retirement in 1933.

The life-long interest of Mr Jack was the study of archaeology, and he wrote several books and numerous Papers on the various excavations made in Herefordshire.

From his retirement until 1945 he was Consultant to the Council for the Preservation of Rural England.

Mr Jack was elected a Member of the Institution in 1916.

He was also Fellow of the Royal Institute of British Architects, a Fellow of the Geological Society, and a Fellow of the Society of Antiquaries.

He leaves a widow and a son.

PROFESSOR FREDERICK CHARLES LEA, O.B.E., D.Sc., who died on the 30th September, 1952, at the age of 81, at his home at Dore, Sheffield, was born in Crewe, Cheshire, on the 25th June, 1871.

He began his education at Crewe School, and before going up to a university served an apprenticeship (1887–92) in the Mechanical and Electrical Departments of the London and North Western Railway's Works at Crewe. On the completion of this part of his training he went, in 1892, to Owens College, University of Manchester, leaving in 1893 to proceed, with a Whitworth Exhibition, to the Royal College of Science, London, where he obtained his Associateship in 1896, obtaining first-class honours in both Physics and Mechanics.

On leaving College, in 1896, he spent two years as an Assistant in the Civil Engineer's office of the London and North Western Railway Company's Works at Crewe.

However, it was the teaching, more than the practice, of engineering that attracted Professor Lea and in 1898 he took up the first of the many important academic appointments in which he was to distinguish himself, namely, Chief Assistant to Professors Unwin and Dalby at the City and Guilds College, London. During the twelve years he held this post Professor Lea published valuable Papers, mainly on structures, and developed that bent for research which has characterized his subsequent career.

He remained in this post until 1911, leaving to spend two years as Chief Engineering Inspector to the Board of Education. In 1913 he was appointed Professor of Civil Engineering at the University of Birmingham, and in 1913 was chosen to fill the Chair of Mechanical Engineering at the

University of Sheffield, from which he retired in 1936; on doing so he became a Director of Edgar Allen & Co. Ltd, Sheffield.

In the 1914–18 War he held a Territorial Commission and Commissions in both the R.N.V.R. and R.F.C. He made many valuable contributions to aeronautical research, in recognition of which he was awarded the Order of the British Empire. For a Paper relevant to his work on aeroplane engines he was awarded the Bernard Prize of the Institution of Mechanical Engineers in 1924.

Although Professor Lea's academic interests ranged over many fields of engineering study, he will best be remembered for his study of structures, and hydraulics, of which latter he was acknowledged to be an authority of the first order; his book, *Hydraulics*, first published in 1908, ran through several editions.

Professor Lea was elected an Associate Member of the Institution in 1901, and was transferred to the class of Member in 1918. He read many Papers before the Institution, gaining him Telford Premiums in 1905,[1] 1911,[2] and 1938,[3] and also a Crampton Prize in 1920.[4]

He was also an Honorary Member of the Institution of Mechanical Engineers (President, 1943), and a Member of the Institution of Structural Engineers.

He leaves a widow and two daughters by a previous marriage.

ARTHUR CLIFFE WALSH, who died on the 18th June, 1952, at his home in Bournemouth at the age of 74, was born at Halifax on the 29th January, 1878.

He was educated at Hipperholme Grammar School, Halifax, Yorkshire, and at Mason's College, Birmingham (now part of the University).

From the outset of his professional career he devoted himself to the study of docks and harbour construction, and on leaving College in 1896 was, until 1899, Assistant Engineer on the construction of Port Talbot Railway and Docks. The following two years were spent, in a similar capacity, on the construction of Seaham Harbour and Docks.

In 1902 he was appointed Sub-agent to Sir Henry Japp during the construction of the Great Northern and City Railway (from Moorgate Street to Finsbury Park, London).

In 1904 he joined the firm of S. Pearson and Son, with whom he was to remain for many years, and to gain further experience he spent four years in Malta, as Sub-agent and Engineer for this company during the construction of the National Harbour and Docks. Returning home in 1908,

[1] Min. Proc. Instn Civ. Engrs, vol. 161 (1904–05, Pt III), p. 261.
[2] Min. Proc. Instn Civ. Engrs, vol. 185 (1910–11, Pt III), p. 277.
[3] J. Instn Civ. Engrs, vol. 7, p. 119 (Nov. 1937).
J. Instn Civ. Engrs, vol. 9, p. 301 (June 1938).
[4] Min. Proc. Instn Civ. Engrs, vol. 209 (1919–20, Pt I), p. 394.

he spent the following four years in the London office of his firm, working on harbour work design, under Sir Ernest Moir, Bart.

In 1909, the firm lent Mr Walsh as engineer to a party of explorers, who went to Jerusalem, hoping to discover the Ark of the Covenant. An account of that expedition is given in Lieut.-Col. Cyril Foley's book, "Autumn Foliage."

In 1912 he again went abroad, and spent the succeeding eighteen years in Chile. The first thirteen years were spent as Engineer-in-charge of the construction of the Valparaiso Port works—a vast project costing £3 million. On the completion of the Port works in 1925, he was appointed Managing Director of two nitrate companies in Chile, owned by the Pearson group.

Returning to England in 1930, he was appointed Managing Director of Messrs Pearson and Norman Long and Co., a company principally occupied in sinking and working two large collieries in south-east Kent. Although Mr Walsh retired from the managing-directorship in 1937, he retained his seat on the Board of Directors.

Mr Walsh was elected an Associate Member of the Institution in 1904 and was transferred to the class of Member in 1922.

He was awarded a Miller Prize in 1901 for a Paper on the "Construction and Working of Blockyards in connexion with Seaham Harbour and Breakwater," and in 1922 was awarded a Telford Premium for his joint Paper with Mr W. F. Stanton, "Improvement of the Port of Valparaiso."[1]

He leaves a widow and a daughter.

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[1] Min. Proc. Instn Civ. Engrs, vol. 214 (1921–22, Part II), p. 3.

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